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THE Association was organized in Boston, Mass., on June 21, 1882, with the object of providing its members with means of social intercourse and for the exchange of knowledge pertaining to the construction and management of water works. From an original membership of only TWENTY-SEVEN, its growth has prospered until now it includes the names of over 1000 men. Its membership is divided into six classes, viz.:

A Member shall be an officer or employee of a public or private water works, an engineer, chemist or other person qualified to aid or interested in the advancement of knowledge relative to water works.

An Honorary Member shall be a person of acknowledged eminence in some branch of water supply or of engineering.

A Junior shall be not less than eighteen years nor more than twenty-five years of age, a student or connected with water supply work.

An Associate shall be either a person, firm or corporation engaged in manufacturing or furnishing materials or supplies for the construction or maintenance of water works.

A Corporate Member shall be either a Water Board, Commission, Company or Municipal Corporation.

The initiation fees and annual dues are as follows:

	Initiation Fees	*Annual Dues*
Members	$ 5.00	$ 8.00
Juniors	1.00	3.00
Associates	10.00	25.00
Corporate Members	10.00	15.00

This Association has at least eight regular meetings each year, of which five are held in Boston, one in northern New England, one in southern New England, and one, the annual convention, held in September or October on such date as the Executive Committee may designate.

Horse and buggy transportation in the jet age...

When rapidly increasing population and industrial demands are making water consumption *soar like a jet,* are your water officials forced to go along, horse and buggy fashion, with facilities designed to accommodate a previous generation?

If so, your most immediate needs are new and bigger pipe lines to supplement the old and to replace the obsolete. LOCK JOINT CONCRETE PRESSURE PIPE is the ideal material to implement this important program. Its durability and dependability assure trouble-free service for generations to come. Its initial high carrying capacity is a permanent feature, permitting accurate, long-range estimates of available supply in the distant future.

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America's greatest water carrier

Installation of 2000 feet of 12-inch mechanical joint cast iron pipe along state highway.

Why do we say that?

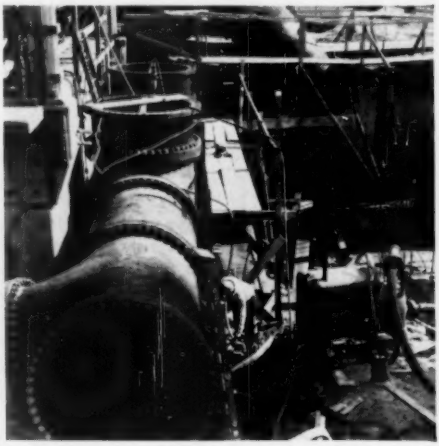
This year, as every year, more miles of underground cast iron water mains are in use than all other kinds of pipe combined.

Furthermore, more miles of cast iron water mains are now being purchased and laid than of any other kind of pipe.

Yes, cast iron is always the favorite. A recent impartial survey showed that consulting engineers and water utility officials prefer cast iron pipe for underground water distribution by an overwhelming majority.

Cast Iron Pipe Research Association, Thos. F. Wolfe, Managing Director, 3440 Prudential Plaza, Chicago 1, Ill.

Eight-inch cast iron pipe ready for installation of 2-main water system in new subdivision.



Installation of 60-inch flanged pipe and fittings for circulating condenser water in a power plant.

Additions to a municipal water system totaled 116,080 feet of slip-on joint cast iron pipe in 6-, 10- and 12-inch sizes.

Private water company main extension of 6-inch slip-on joint pipe for housing development.

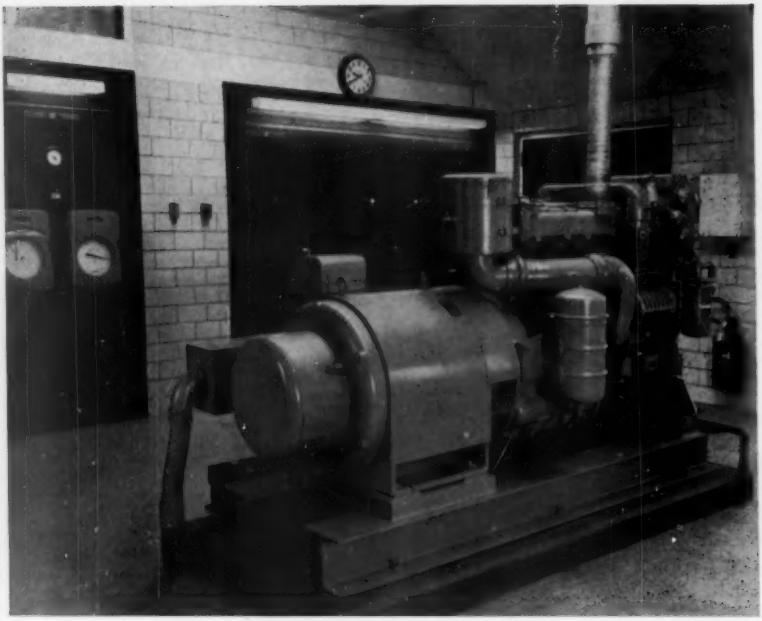
What are its advantages?

- *Long life.* The cast iron pipe you install today will be performing economically a hundred years from now.
- *High-capacity flow.* Cement-lined cast iron pipe will deliver the full-rated flow all through the years. No other pipe, size for size, can carry more water.
- *Corrosion resistance.* Long life proves it. Most water utilities are still using the first cast iron pipe they installed.
- *Great beam strength.* Cast iron pipe resists the effect of heavy traffic, shifting soils.
- *Tremendous load resistance.* Six-inch cast iron pipe (Class 150) withstands a load of nearly nine tons per foot!
- *Pressure-tight joints.* You have a complete choice of leakproof, easy-to-assemble joints. You need a minimum of tools and work crew.
- *Ease of tapping.* No tapping saddles needed. Takes threading best of all kinds of pipe.

...good reasons for <u>you</u> to choose

CAST IRON PIPE

THE MARK OF THE 100-YEAR PIPE



Diesel Generator Set
Brunswick and Topsham Water District
Brunswick, Maine

This 125 KW CUMMINS Diesel Generator Set provides stand-by power at Taylor Farm Supply, Brunswick and Topsham Water District. The generator set is specially designed to start a 100 HP pump motor.

Camp, Dresser and McKee of Boston, Massachusetts, were the engineers for this unusual application of diesel power.

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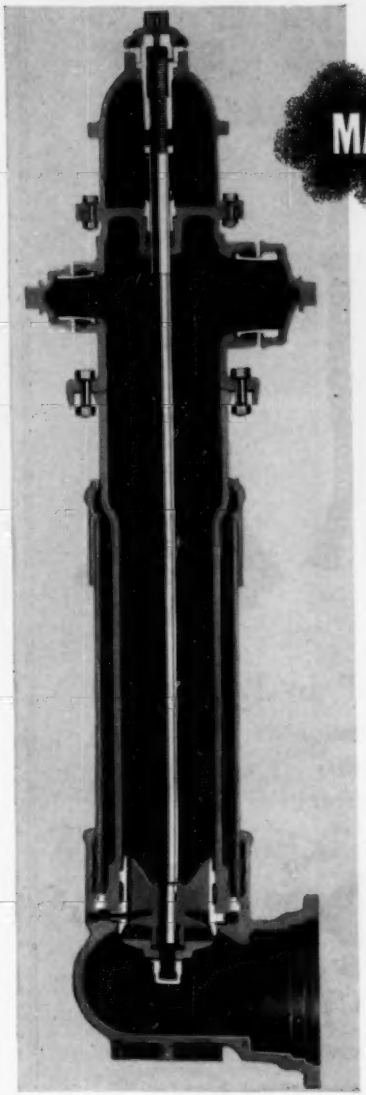

MATHEWS HYDRANTS

The Mathews Modernized Hydrant Supplies the 4 Fundamental Requirements for Effective Community Protection

and many other quality features, too

- Replaceable barrel for maximum efficiency—quickly replaced in case of accident without excavating
- Head revolves 360°; simply loosen bolts and rotate
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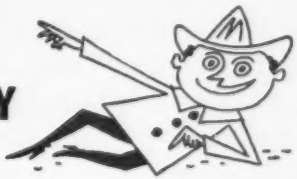
- Operating thread, protected by stuffing box plate, operates free of rust, sediment and ice

Also . . . Nozzle sections supplied with hose or pumper outlets as specified • Operating thread cannot be bent • Compression-type main valve prevents broken Mathews from leaking • Nozzle level can be raised or lowered without excavating • Bell, mechanical-joint, or flange-type pipe connections • Conventional or "O" ring packings



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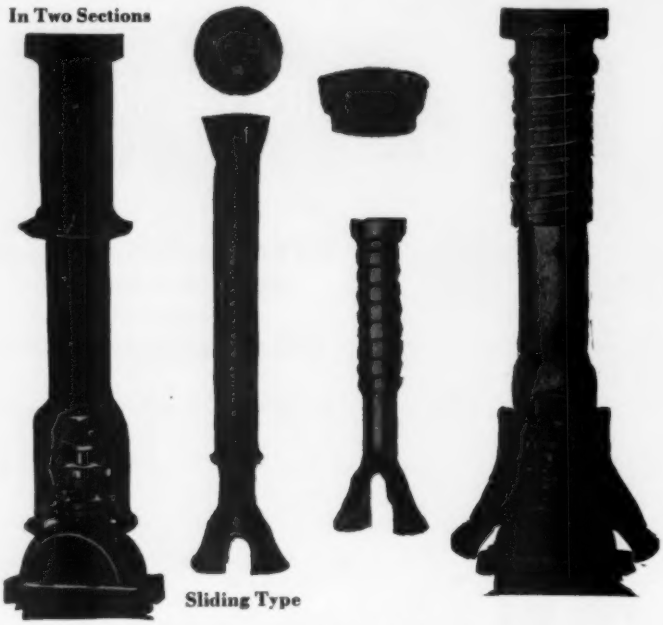

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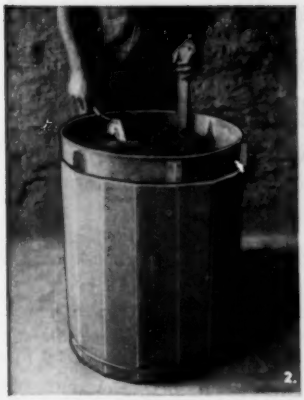


1. Large illustration shows Singl-use Fiberform ready to be filled.
2. Filling plate and collar simplify pouring concrete into form.
3. Completed meter box barrel.
4. Meter box with cover in place.

FOR ECONOMICAL SETTINGS

Make Your Own

CONCRETE METER BOX BARRELS *with* FORD *Singl-use Fiberforms*

Water utilities that find vitrified or concrete tile expensive or difficult to obtain, may now make their own barrels for outside meter settings with Ford Singl-use Fiberforms which are inexpensive and easy to use. Forms made for 15", 18" and 20" ID barrels and in lengths of 15", 18" and 24". Use two for deep settings. Send for full information.

FOR BETTER WATER SERVICES

FORD

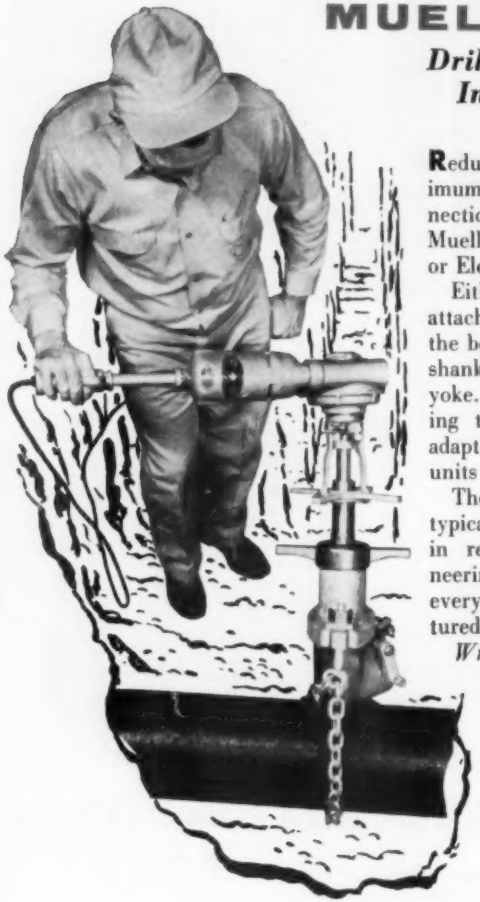
THE FORD METER BOX COMPANY, INC. Wabash, Indiana

Drill and tap a ¾" hole in three minutes!

use the power-operated

MUELLER® *B-100*

Drilling, Tapping and Inserting Machine



Reduce time and effort to a minimum on all of your service connection jobs by using the new Mueller B-100 Machine and Air or Electric Power Operator.

Either type of power operator attaches directly to the top of the boring bar *and* to the square shank on the top of the feed yoke. Tool feed is automatic during the drilling operation. No adapters are needed and both units are reversible.

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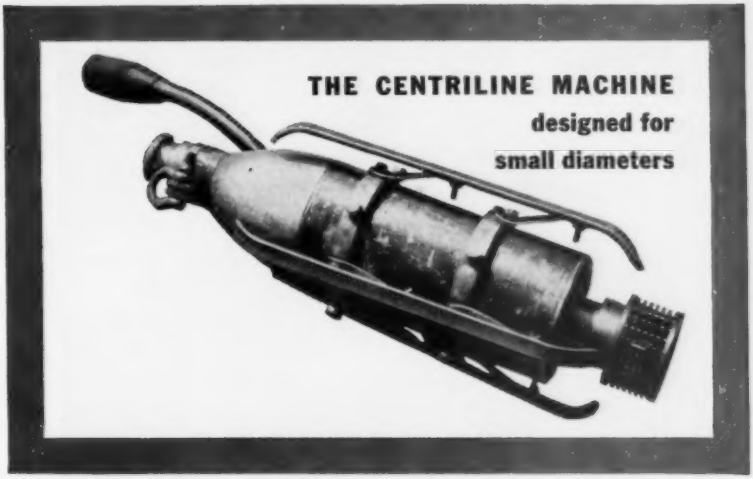
NOW! THE CENTRILINE PROCESS is available for 6" to 14" mains, too!



Yes, your city's small but important transmission and distribution lines can also regain their original flow capacity and pressure through the universally accepted Centriline Process of centrifugally applying a cement-mortar coating to the pipe walls. If some of your lines inadequately serve your customers' requirements, including higher demands for fire protection, investigate the numerous advantages of Centrilining your mains now.

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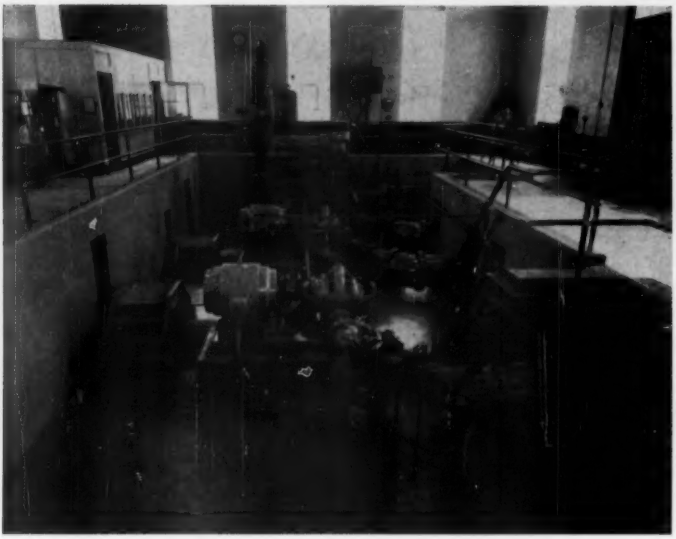

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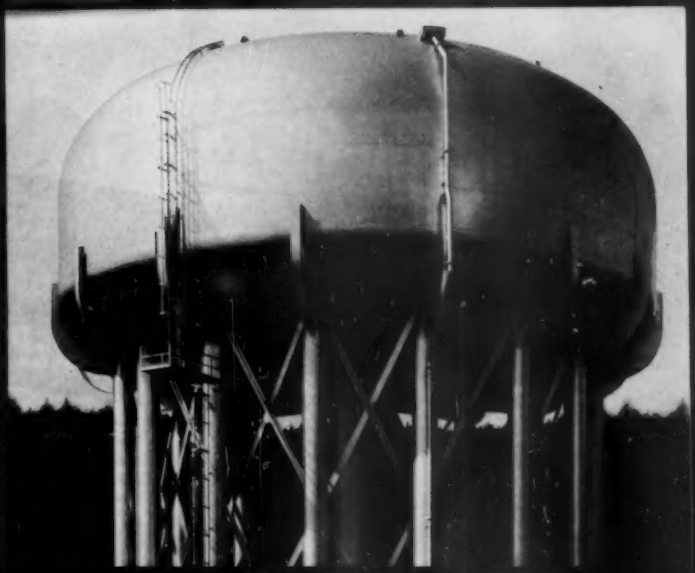

Radial cone tank, Seattle, Wash. Capacity 2,000,000 gallons.

FIRST IN EXCELLENCE

TO SERVE DEPENDABLY THE WATER STORAGE NEEDS OF MODERN AMERICAN COMMUNITIES

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From the first PDM Elevated Steel Tank, pioneered in 1897, to the handsome structures of the present, *first quality* has been our continually-realized objective. You'll find in the wide range of PDM tank types and capacities the ideal unit for your requirements—guaranteed in performance and satisfaction. Let us submit a quotation.

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Radial cone tank, Independence, Kansas. Capacity 750,000 gallons.

Double-ellipsoidal tank, Melbourne, Fla. Capacity 300,000 gallons.

Pedestal sphere, Hawthorne, Calif. Capacity 250,000 gallons.

WRITE FOR this fully-illustrated 28-page "Modern Water Storage" brochure—detailing the range of PDM Elevated Steel Tanks. Free on request to our nearest office.

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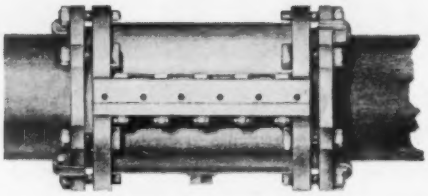
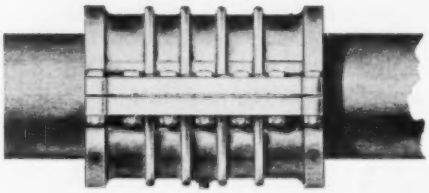


Mechanical Joint Repair Sleeve



Bell (Hub) End Repair Sleeve

INSTALL A SMITH SLEEVE

Smith Repair Sleeves are the answer to permanently repairing and quickly returning broken and cracked piping to service. Two types of Smith Repair Sleeves are available for installation on standard classes of cast iron pipe. Smith Mechanical Joint Repair Sleeves are produced in sizes 4″ thru 12″; Smith Bell (Hub) End in sizes 4″ thru 48″. Unskilled labor can speedily install Smith Mechanical Joint Repair Sleeves even in wet excavations. Bell End Repair Sleeves are most frequently installed with caulked lead joints. Smith Repair Sleeves reenforce the broken — cracked pipe and their service life equals the life of the pipe.

63

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THE A.P. SMITH MFG. CO.

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WHEELER HYDRAULIC PIPE CUTTER

NO VISE — NO TURNING — JUST SQUEEZE AND POP!

Cutter can be used in a ditch to cut pipe in a line with minimum clearance. All that's required is room to wrap the chain around the pipe.

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— less than 2 minutes per cut —
a one man operation.

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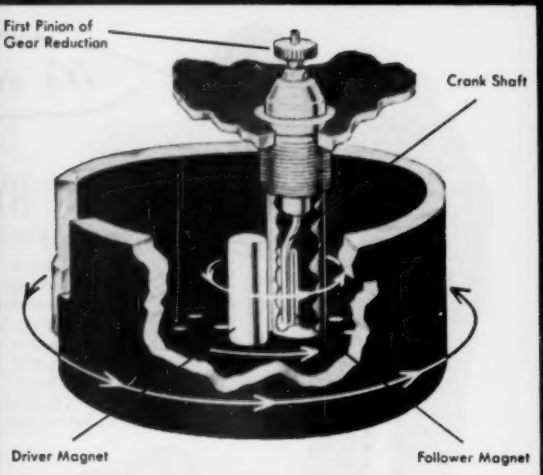

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Now available
in both 5/8"
and full 3/4" sizes

SEALED REGISTER METERS
another fine product by
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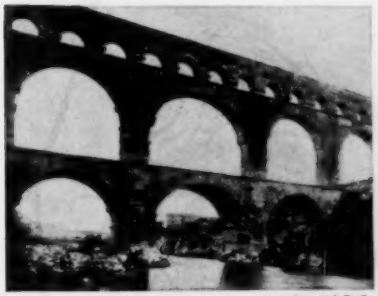
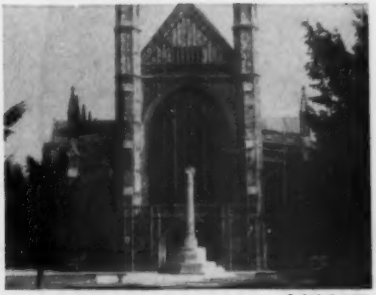


Aqueduct, 105 B. C.



Cathedral, 1065

Fountain, 1650

Ludlow Hydrant, 1883

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In a sense, Ludlow and Rensselaer fire hydrants are among the great man-made objects. They're built to *last*. All Ludlow and Rensselaer hydrants are made to stay on the job through years of rough treatment and rigorous climate —never quitting!

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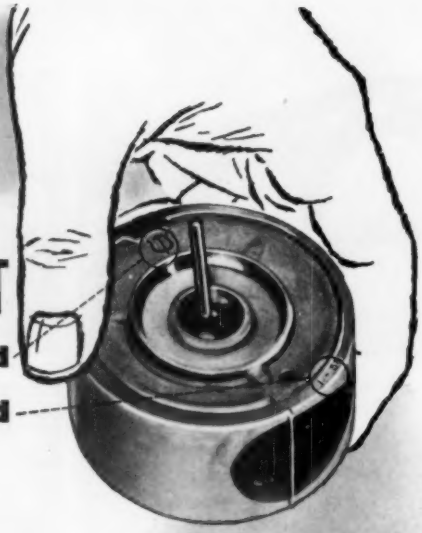

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EVERYDAY IS SATURDAY TODAY. With clean, pure water . . . carried through cast iron pipe . . . the shower or bath today is an accepted part of American living.

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Mine-to-main control assures
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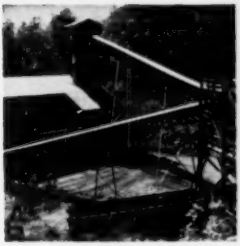
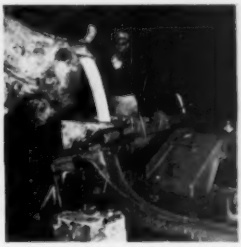
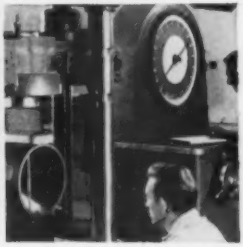


CLEANING ORE. U. S. Pipe ore cleaning plant at a mine where ore is crushed and passed through separators to float off impurities.



MOLTEN IRON in a measured amount is poured into a machine ladle, preparatory to the start of the centrifugal casting cycle.



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WATER-WORKS ACCOUNTING

BY RICHARD G. SMALL*

[*Read September 17, 1958.*]

Accounting has grown into a science of utmost importance in our modern world of complex economics.

One might ask, "In a business function, where does accounting come into the picture?"

To accomplish anything there are three phases of activities:

1. "Determinative phase," whereby an objective is defined.
2. "Applicative phase," whereby the objective is obtained by functioning.
3. "Interpretative phase," whereby the objective defined and the accomplishment are studied for historical value.

Accounting comes under this last phase, though it may, and most desirably, be carried on concurrently with the activity for control. And perhaps coming last, as it must, is one reason why this science has been so late in developing and coming to maturity.

Great things have been accomplished in this world by creative minds having ideas and then converting these ideas into real and practical goods and services. But the process does not stop there. As the progressive nations have developed and become more populated, internal and external competition has required that the producer of goods or services study, interpret and control his production.

Accounting encompasses a wide area. In a water utility, it is from the reading of the meter in the field to the billing of the customer; from the collection of the cash to the spending for the myriad of goods and services required to keep a water utility operating; and from the borrowing of money by means of notes,

*Assistant Treasurer, Portland Water District, 16 Casco St., Portland, Me.

bonds, etc., to the disbursing of such funds for expansion projects.

What accounting is:

Accounting is defined as the recording, analyzing and reporting of transactions of a financial character with a built-in system of control. It is to be distinguished from bookkeeping, which concerns itself mainly with the process of studying, classifying and recording transactions according to a prescribed procedure. Accounting precedes bookkeeping in the devising of methods of recording transactions and in the instituting of internal controls and checks. It controls bookkeeping in its constant program of testing and reviewing the records through internal and external auditing. And lastly, accounting performs perhaps its most valuable function where bookkeeping stops—that of reporting and interpreting the results of the recordings of transactions.

Thus, we have the three main phases of accounting:

1. Systems;
2. Records and Controls;
3. Reporting.

* * * *

"Water-Works Accounting" is a vast subject to try to cover in a few minutes. If we had an all-day session on this subject alone, the program could alternate between two themes:

1. Principles of Water-Works Accounting, and
2. Procedures for Water-Works Accounting.

But for this paper, we shall be concerned mainly with principles of water-works accounting and trust that "accountants' round-table" sessions will follow some day to explore further these principles and consider procedures to be followed in the application of these principles.

* * * *

The whole purpose of accounting is to provide control—control for those who are responsible for the general policy-making. It may be a board of trustees, the city council, or a board of directors, but in any case, it is for the person or group

operating at the first and highest level, at the "determinative phase." Accounting is for providing control for those who are responsible for administration and operation, these coming under the "applicative phase."

Accounting provides the interpretation of financial transactions relied upon by owners, management, labor, customers, and the general public. It is the function of the accountant to be always striving to better this interpretation. In doing this, he may sometimes be misunderstood. I am reminded of the Italian immigrant who had just come to the United States and went with a friend to his first ball game. He liked it fine, but he couldn't understand the umpire. He described him this way: "He no hit, he no catch, he no throw—he justa maka trouble."

Occasionally to some on the operating level, whose activities are being studied, the accounting department may seem like the umpire.

To have accounting serve its function, it must be clothed with proper organization. The accounting department should be set up to meet the same basic requirements as those of the overall business organization. They are to aid in:

1. The delegation of authority;
2. Communication, both to and from above and below, and,
3. Assuring accountability.

Whenever size permits, a professional accountant should head the accounting division, with definite lines of responsibility and authority. If the utility is small, and the work cannot justify such a person, then management should look to public accountants to perform the functions that a full-time accountant in a larger utility would perform. Heretofore, public accountants have concerned themselves mainly with verifying records and preparing statements. But today, by demand, a good public accountant has broadened his activities to be of more service to management. In fact, in the March, 1958, issue of "The Journal of Accountancy," a publication of the American Institute of Accountants, there is an article entitled "Ethical Considerations in Rendering Management Services," written by Ira N. Frisbee, C.P.A. These "management services" refer to any service for

management of fact-finding or advisory nature, except financial auditing and tax work.

I believe this fact is important to stress here, because so many of our water utilities are relatively small. If your public accountants are giving only verification and statements, you may have much to gain by requesting more from them or seeking another who can deliver for you. Of course, if you want more, you will have to pay for it, but from my own observations the price would be but an investment resulting in savings which multiply. To quote from "Professional Ethics" by D. V. House, F.C.A., in "The Accountant" (England) of October 20, 1956:

NECESSARY EXPENSE OR PROFITABLE INVESTMENT?

"One way of ensuring satisfied clients, willing to pay adequate remuneration for the services rendered, is to see that we always give the best and widest service we can. There are still many who regard us as a necessary nuisance born of company law and complicated taxation legislation. We shall only foster that feeling if we confine our services to the strict needs of an audit and the agreement of taxation liabilities. A great many clients, particularly the smaller businesses, could gain great benefit from a full report on the position shown by the accountants and from advice on administration problems and the use that can be made of suitable accounting records for management purposes. A client who, through our extra efforts, realizes that we can be not only a necessary expense, but also a profitable investment, is more likely to appreciate the need for adequate remuneration."

This quotation reflects the trend of thinking by public accountants everywhere.

Beyond setting definite lines of authority and responsibility, which is the function of top management, the accountant then must organize the work and personnel. In an established organization, the work flow must be studied and compared with the characteristics of a good system.

This brings us to the phase of accounting mentioned earlier: that of systems. Rudyard Kipling described very aptly what is involved in studying systems:

"I keep six honest serving-men,
(They taught me all I knew)
Their names are What and Why and When
And How and Where and Who."

The objective of a systems study is the establishment of records which will readily yield information needed for reporting to interested parties.

A system of records and reporting should be considered with the following principles:

1. The objective* in accounting is the classification, recording, summarization, and reporting of the transactions of individual entities (as in the case of the Portland Water District, which supplies three cities and seven towns, each an entity in itself) in terms of revenues, transfers, and costs, including the conversion of costs into cash (the expense-revenue cycle) and other assets (such as distribution mains), and their dissipation as expense or loss (which intimates depreciation).
2. Because management* has the ever-present obligation of striving for and maintaining lowest possible cost, much of the accounting process is constructed with the view of that obligation.
3. The system should be simple, and over-elaboration should be avoided. The validity of the system depends not on the quantity of records and personnel involved, but rather on the type of system and its results.
4. The system should be flexible, sufficiently elastic as to meet the demands of a changing and developing business.
5. The system should be balanced: not overlapping with resulting duplication, but on the other hand not leaving important "cost areas" unaccounted for.
6. The system should be on the "accrual basis." This is to say, all expenses are entered onto the books as incurred. All revenues are accounted for when earned. *When* the cash is paid or received is not the primary consideration in statements. But rather, *what*, as of a given date, is the status of the business as reflected by the balance

*"A Dictionary for Accountants," by Eric L. Kohler, Prentice-Hall, p. 11.

sheet, and *what* was the progression for a given period as reflected by the profit and loss statement.

The accounting system should start as near as possible to the activity for which it accounts. For example, in the engineering, construction, and operation departments, each job should be covered by a work order, which is simply a written record showing what shall be done, pertinent information, work-order number, account to be charged with the costs, and division (if more than one division is served by the utility, and costs by division are desirable). The varying types of work orders necessary depend on the size of the utility. In a smaller utility, one type of work order could serve for all "fixed capital" work, where in a larger firm, mains may require one type, services another, etc.

For labor, each employee is covered by a time card on which is entered the hours worked with the account number, work-order number, and division, if applicable. The card may serve for a day or a week. It may be kept by the employee, his foreman, or a timekeeper.

After each pay period, the time cards are sent to general accounting, where the rates are applied and extended. The payroll check is then prepared. The extensions on the time cards showing the amounts chargeable to each account and work order are distributed to the work orders and the "payroll journal." A journal is simply a "book of original entry," where like charges are brought together for a period, as a month, for summary entering into the general ledger.

An account is a medium for collecting like costs to be shown in a financial statement. The general ledger is a collection of such accounts. There are two types of accounts: "real" accounts, which are the balance-sheet accounts, and which normally have balances to be carried forward each year. "Nominal" accounts, or profit and loss accounts, are used to collect costs for one period, as a year, and are closed out to surplus. The public utility commission of each state prescribes the account titles and numbers.

* * * *

The materials used on a job are listed on the work order by the foreman. At the end of the week or upon completion of the

job, he turns the order in to the stock clerk, who compares the materials used with his "stock issuance" slip. If the two agree, the order is sent to "general accounting," where it is priced and entered into the "work order journal," the proper account being charged and the appropriate accounts credited for the materials used.

An efficient method of accounting for the use of construction equipment on jobs is to have the foreman list the equipment with hours of use on the work order at the same time that he accounts for his materials. The accounting clerk applies a predetermined hourly rate, then extends and enters it into the "work order journal," charging the proper account and crediting the "clearing accounts."

A "clearing account" is a medium for collecting desired costs to be distributed or transferred to other accounts. In the case of an equipment clearing account, the costs of operating the equipment (excluding the operator's time) are charged to that account, and credits are given representing use of equipment. Ideally, the account should be zero at the end of the accounting period or year.

With every direct cost chargeable to a work order, there are indirect costs which benefit the job and, therefore, are chargeable to the job. For example, to the dollars paid directly to labor for a job, there are fringe costs such as pension, insurance, welfare, and workmen's compensation. Also, to put a laborer on the job requires a shop from which to operate, a stock room for materials, supervision, and office expenses which are definitely correlated with the activity in the "operation and construction" department of the utility.

One effective way of distributing these costs to jobs and accounts is to use the medium of an "overhead rate."

The rate is simply the ratio of the indirect costs to the total number of units which best reflect the measure of production or work performed. Thus, the formula is as follows:

$$\text{Overhead Cost Rate} = \frac{\text{Overhead Costs}}{\text{Number of Units}}$$

Units commonly used are direct labor hours or direct labor dollars. In most cases the costs are best related to the direct

labor dollars. "Direct labor" refers to the labor incurred through the operation, maintenance and construction of the water system. Excluded is the general office and administrative labor.

To illustrate the accounting, let us consider a new service installation where the labor amounts to $100. On the work order is applied the overhead rate, which may be 40%. For the sample service then, we would apply the overhead rate of 40% or $40 and the entry would be as follows:

Dr. 373 Services
Cr. 145 Overhead Applied
To charge service with overhead costs.

At the end of the year, the 145 "Overhead Applied" account is closed out to the expense accounts, which include the costs considered in the computation of the rate. The entry is as follows:

Dr. 145 Overhead Applied
Cr. Applicable expense accounts
To close out overhead applied.

* * * *

Thus far, we have briefly considered the accounting for labor, materials and overheads, and their connection with the "payroll journal" and the "work order journal."

In addition to these journals, there are the following:

Voucher Register: The voucher register is a journal for the entry of vouchers, usually showing the date, name, and voucher number, the total amount being entered in a credit column entitled "vouchers payable," with additional columns permitting distribution and summarization of the vouchers for entering in the general ledger.

A voucher is an accounting unit generally comprising a voucher jacket, invoice and receiving slip. The jacket contains the following information:

1. Vendor's name and address;
2. Total payment;
3. Dollar and account distribution;
4. Authorization for payment;
5. Check number;
6. Voucher number.

In most commercial businesses, the vouchers are filed alphabetically, but in a water utility, where so many of the vouchers are for additions to plant, which is long-lived, there is merit in filing the vouchers numerically.

Cash Journal: The cash journal is a record showing items or transactions affecting the cash account.

Revenue Journal: The revenue journal is a record of the charges of revenue, showing the debits to Accounts Receivable and credits to the various types of revenue.

Journal Vouchers or General Journal: The general journal is for recording transactions not provided for in specialized journals.

* * * *

To reiterate, the journals arrange basic information coming from the time cards, work orders, cash reports and other original documents for ease of entering in the general ledger. The general ledger contains the accounts which readily supply information for the financial statements.

The following are some financial statements and reports beneficial to management:

Monthly: Balance Sheet
Comparative Profit and Loss Statement

Annually: Debt Survey (with 20-year forecast of debt-service charges)
Fixed Asset Survey related to Reserve for Depreciation
If the utility is serving more than one division and if desirable, a Profit and Loss by Divisions

Miscellaneous Reports:

Cost-per-mile Statement for Vehicles
Cash Budget and Forecast
Rate-Case Schedules and Exhibits

* * * *

Up to now we have considered:

1. Where accounting comes into play;
2. What accounting encompasses;
3. What accounting is.

There is much more that can be included. There is the rate structure; ways of financing and administering the debt; customer billing and accounting; control of fixed assets; inventory management; and so many more special areas which are comprehensive, interesting, and challenging. It is not here in the discussion of principles that any material gain or benefit may be directly realized, for it is in the analysis of procedures that real, tangible benefits may be gained. But principles must be studied, tested and agreed upon before it is practical to consider procedures. It has been and still is my hope that within our New England Water Works Association accounting principles and procedures will occupy a more prominent arena.

* * * *

One final point deserves our attention. Accounting is a profession. A profession has been defined as consisting of four elements:

1. Special training recognized by universities and colleges;
2. Consisting mainly of mental rather than manual or artistic labor and skill;
3. Recognition of responsibility to public service, and
4. A code of ethics generally accepted as binding upon its members.

There is a greater responsibility to public service on us as accountants in water utilities than there is on our colleagues in industrial accounting. Recognizing this, we, with the aid of top management, must continue to foster existing programs of professional development and to institute new programs where none now exist.

There are several excellent organizations which are devoted to the furtherance of the accounting profession. To list a few:

National Office Management Association
(Ten chapters in New England)

National Association of Accountants
(Chapters in or near most large cities)
American Management Association

The requirements for professional development can be broken into five component parts:*

1. Personal identity and recognition are of utmost importance.
2. A man must have internal executive and management training which will qualify him for future use.
3. A man must be encouraged by his firm to take the necessary time to do his part in civic, state and national activities affecting his profession, his community, his church, and his fellow man.
4. A man must be encouraged by financial support from his firm to participate fully in professional activities.
5. A man must be instilled with a desire to contribute to the profession through service, published articles, speeches, or research—the first requirement of a profession.

As already mentioned, top management plays a vital part in these programs, particularly in the financial support. But top management in its appraisals must be given assurance of the value of these activities. Our contributions as accountants must give that assurance.

*"Professional Development," by Wm. P. Hutchinson, C.P.A., The Journal of Accounting, Nov., 1957.

TASTE AND ODOR PROBLEMS IN THE UNITED STATES

BY E. A. SIGWORTH*

[*Read at Chemists' Session, Nov. 20, 1958.*]

The 1958 meeting of the International Water Supply Congress included in its program a panel discussion on "The Control of Odor and Taste in Water Supplies," and the writer was delegated as reporter for the United States on this subject. In order that the report might be more than just one person's opinion, questionnaires were prepared on various phases of the subject for submittal to water-works officials concerned with the problem. Selection of individual plants was greatly simplified by data contained in a survey conducted by the United States Public Health Service, encompassing water facilities existing in communities of 25,000 population or over.

This survey reported that 202 plants, out of 570 total, were employing corrective treatments for taste and odor control. These specific plants, therefore, constituted a core for development of the desired information. To broaden the scope of the coverage, questionnaires were submitted to additional plants where corrective treatments such as activated carbon, free-residual chlorination, and chloride dioxide had been utilized for improvement of water palatability. Responses were amazingly good, totaling 241 and representing a return of better than 65%.

Since algae are the most frequent cause of tastes and odors, a separate questionnaire was submitted to those reporting algae as a problem. Responses to this algae questionnaire were less numerous, because some plants were not equipped to make microscopic examinations, or had little concern because the water was a stream or large lake, where treatment would be impractical. Nevertheless, 152 responses were received, and Table 1 summarizes the number of plants reporting experiences with the specific algae types.

The group of organisms most frequently reported is the

*Technician, West Virginia Pulp and Paper Co., 230 Park Ave., New York 17, N. Y.

TABLE 1.—NUMBER OF PLANTS REPORTING EXPERIENCES WITH SPECIFIC ODOR-PRODUCING ALGAE

Diatomaceae	321	*Chlorophyceae*	114
Asterionella	102	Dictyosphaerium	6
Cyclotella	29	Eudorina	16
Diatoma	42	Gloeocystis	9
Meridion	7	Hydrodictyon	5
Synedra	93	Nitella flexilis	0
Tabellaria	48	Pandorina	17
Cyanophyceae	198	Staurastrum	26
Anabaena	91	Volvox	35
Aphanizomenon	52	*Protozoa*	205
Clathrocystis	12	Bursaria	0
Coelosphaerium	29	Ceratium	33
Cylindrospermum	5	Cryptomonas	6
Rivularia	9	Dinobryon	48
Fungi	26	Glenodinium	13
Beggiatoa	6	Mallomonas	23
Crenothrix	19	Peridinium	16
Sphaerotilis natans	1	Synura	66

Diatomaceae, with the *Protozoa* and the *Cyanophyceae* groups practically tied for second. Those in the *Fungi* group are of only minor significance.

Decaying Vegetation

Odors under this classification derive from decaying algae, leaves, weeds or grass; seepage from stagnant areas into reservoirs or streams; flushing of stagnant areas and farm land during spring freshets or heavy rainfall periods, and from any disturbance of bottom deposits in streams or impounded supplies, due to sudden raising or lowering of the water level.

Many reported the types of odors arising from decaying vegetation, and these are summarized in Table 2. It will be noted that the most prevalent descriptive term is musty, while the anticipated descriptions of swampy, wet leaves, and moldy fall far behind. A close examination of the descriptive terms at the bottom of the table will indicate the imaginative character of some of the observers. It is quite within the realm of possibility that many of these odors may actually be due to the presence of actinomycetes.

TABLE 2.—FREQUENCY OF ODOR TYPES DUE TO DECAYING VEGETATION

Characteristic odor	Number of plants reporting
Musty	69
Earthy	28
Woody	20
Moldy	17
Swampy	12
Grassy	9
Fishy	8
Wet Leaves	7

Others mentioned to a lesser degree are septic, muddy, boggy, vegetable, phenol, peaty, rotten, putrid, soaked straw, very sour, varnish, barnyard, and horse urine.

Trade Wastes

Table 3 shows the summary of types of trade wastes causing tastes and odors in water supplies. Phenol is reported most frequently, with chemical wastes second. Trade wastes occur less frequently than odors of natural origin, but often give rise to extremely high odor concentrations. Since some odors within this classification are more difficult to adsorb on activated carbon, higher dosages are required.

TABLE 3.—FREQUENCY OF INDUSTRIAL WASTES CAUSING ODORS

Types of waste	Number of plants reporting
Phenol	38
Chemical	20
Petroleum Oil or Oil Refinery	18

Others less frequently mentioned are dairies, corn-sugar plants, canneries, mine wastes, sulfite paper mills, and vitamin wastes.

Other Causes of Odor

The most frequent listing under this heading is sewage, with 22 reporting. Second is the muddy, earthy type of odor associated with high turbidity, with nine reporting. Less frequently listed are synthetic detergents, actinomycetes, dairy farms, fish, and silt and mud deposits.

Taste and Odor Resulting From Chemical Treatment

The greater majority reported development of odors or tastes due to treatment chemicals. Seventy-nine per cent of those plants having problems reported chlorinous odors. Many of these have corrected the conditions by using chloramines, activated carbon, closer control of chlorine residuals, or dechlorination.

Corrective Treatments

The questionnaire submitted listed treatments as follows: activated carbon, free-residual chlorination, super-chlorination, chlorine dioxide, ozone, aeration and others.

Thirty-four plants volunteered the information that chloramines are employed, sometimes only as a post-treatment, yet in other cases chloramine residuals are carried throughout the entire treatment plant and distribution system. Questionnaire responses would indicate that chloramine treatment has definite merit as an aid toward delivery of palatable water, and several plants reported utilizing chloramines to eliminate instances of chlorinous, nitrogen trichloride, and/or chlorphenol odors.

The degree of success with various corrective treatments is summarized in Tables 4 to 8, inclusive. Table 4 shows the results of reports on algae as a source of tastes and odors. In considering all of the succeeding tables, it is essential to bear in mind

TABLE 4.—ALGAE
(198 OF 241 PLANTS — 82%)

Treatments	Percentage of plants trying specific treatments	Degree of success reported		
		Total	Partial	None
Activated carbon	91%	90%	9%	1%
Free-residual chlorination	64%	14%	44%	42%
Super- and de-chlorination	15%	24%	41%	34%
Chlorine dioxide	24%	14%	25%	62%
Aeration	23%	11%	53%	36%

that the degree of success refers solely to taste and odor correction. For example, many plants report continuance of free-residual chlorination for the greater assurance of delivering safe water, even though it may not aid in producing palatable water.

Out of 241 reporting plants, algae were listed by 198 plants, or 82% of the total. Of the 198 plants reporting algae, 182 or 91% tried activated carbon, 127 or 64% tried free-residual chlorination, 29 or 15% tried super- and de-chlorination, 48 or 24% tried chlorine dioxide, and 45 or 23% tried aeration. It will be noted that a greater majority of the reporting plants tried activated carbon and free-residual chlorination, whereas only a minority tried super- and de-chlorination, chlorine dioxide and aeration.

Each of the individual reports was then recorded as to the degree of success obtainable with various treatments. There was little difficulty in recording those answers which showed complete success or no success whatever. Some plants, however, indicated that more than one single corrective treatment was necessary, and the specific treatments were therefore recorded in the partial-success column.

In the case of the oxidation treatments with chlorine, plants reported occasionally as follows:

1. Odors reduced but not to palatable levels.
2. Odors sometimes reduced, other times unchanged.
3. Odors sometimes reduced, other times intensified.

Such comments were interpreted for this particular report as giving partial success. Those plants which tried the specific treatment are recorded as percentages under the degree of success.

For example, 15% of the 198 plants tried super- and de-chlorination. This was actually a total of 29 plants. Of these 29 plants, 24% reported complete success, 41% partial success, and 34% no success. This same practice was followed for all of the individual treatments throughout the last five tables of this report.

For the correction of tastes and odors due to algae, activated carbon was most successful, with 90% of the plants trying this treatment reporting complete success. Super- and de-chlor-

ination rated second, with 24% reporting complete success. The remaining treatments recorded did not show too favorably.

Table 5 shows 162 of 241 plants, or 67% reporting decaying vegetation as an odor cause. Again activated carbon was

TABLE 5.—DECAYING VEGETATION
(162 OF 241 PLANTS — 67%)

Treatments	Percentage of plants trying specific treatments	Degree of success reported		
		Total	Partial	None
Activated carbon	93%	92%	7%	1%
Free-residual chlorination	66%	16%	43%	41%
Super- and de-chlorination	12%	30%	25%	45%
Chlorine dioxide	26%	14%	25%	50%
Aeration	23%	6%	47%	47%

most successful, showing results somewhat similar to those in the algae table. Super- and de-chlorination and free-residual chlorination showed somewhat better than in the previous table.

Table 6 differs from the two preceding tables in several respects. It will be noted that chlorine dioxide was tried more

TABLE 6.—TRADE WASTES
(92 OF 241 PLANTS — 38%)

Treatments	Percentage of plants trying specific treatments	Degree of success reported		
		Total	Partial	None
Activated carbon	89%	68%	28%	4%
Free-residual chlorination	67%	19%	35%	46%
Super- and de-chlorination	20%	17%	33%	50%
Chlorine dioxide	58%	49%	24%	26%
Aeration	23%	14%	43%	43%

frequently with this type of odor problem than for algae and decaying vegetation. Furthermore, successful results with chlorine dioxide were much higher at 49% than in the preceding tables. The reason for this is that so many of the plants trying chlorine dioxide reported phenol as a problem and indicated complete success with chlorine dioxide. Those reporting only partial success with chlorine dioxide were faced with phenol along with other trade wastes and indicated chlorine dioxide successful on phenol, but not on the other type of wastes. It will be noted also that free-residual chlorination showed up somewhat more favorably than in the preceding tables, whereas the efficiency of super- and de-chlorination dropped off. Also it will be noted that activated carbon fell off appreciably in the complete-success column, with only 68% reporting.

Table 7 reverts very close to the table on algae, wherein activated carbon was highly successful. One notable exception

TABLE 7.—OTHER CAUSES OF ODOR
(55 OF 241 PLANTS — 23%)

Treatments	Percentage of plants trying specific treatments	Degree of success reported		
		Total	Partial	None
Activated carbon	98%	87%	9%	4%
Free-residual chlorination	71%	28%	31%	41%
Super- and de-chlorination	18%	20%	30%	50%
Chlorine dioxide	38%	14%	10%	76%
Aeration	25%	7%	50%	43%

is the greater efficiency reported for free-residual chlorination at 28% completely successful. Sewage was most frequently reported under this classification and free-residual chlorination is very effective in the elimination of hydrogen-sulfide odors associated with sewage. This explains almost entirely the success reported from this particular treatment. It is difficult to explain the 76% of the trials of chlorine dioxide recording no success whatever.

Table 8 is an over-all summation of the four preceding tables, involving 1,163 cases. In other words, a plant would report trying activated carbon, free-residual chlorination and chlorine dioxide for algae odors, which would represent three cases in this report. If we consider that this plant might face four or five different types of algae, the number of trials would actually have been 12 to 15. Therefore, it is quite within the realm of possibility that the number of cases tried in this summation could be in excess of 3,000.

TABLE 8.—OVER-ALL SUMMATION
(1,163 TOTAL CASES)

Treatments	Percentage of trials of specific treatments	Degree of success reported		
		Total	Partial	None
Activated carbon	40%	86%	12%	2%
Free-residual chlorination	29%	17%	41%	42%
Super- and de-chlorination	7%	23%	34%	43%
Chlorine dioxide	14%	25%	21%	54%
Aeration	10%	9%	49%	42%

In the first column of data, it will be noted that 40% of the 1,163 trials involved the use of activated carbon, or approximately 450 trials. This means that of the 241 reporting plants, activated carbon was tried on the average on almost two different odor causes per plant. Of the other treatments, free-residual chlorination was most frequently tried, followed by chlorine dioxide. The other two treatments were rather infrequently tried. This summation has value to the consulting engineers and chemists who are facing a treatment problem on a water supply with no previous historical background on odorous conditions. It probably is of more value than any of the individual preceding tables, because it does give a greater cross-sectional view of the specific treatments for the over-all situation. For the interpretation of data of this type a large number of reports is necessary, to obtain a cross-sectional view.

For example, super- and de-chlorination was tried in only

7% of the cases, or approximately 80 trials. Therefore, these 80 trials are much more meaningful than is true of the preceding tables, because of the small number of trials for this specific treatment. From the viewpoint of total success, activated carbon is far in the lead with 86%; chlorine dioxide rates next with 25%, followed by super- and de-chlorination at 23%, free-residual chlorination at 17%, and aeration at 9%.

Summations

Although great strides have been made within the United States in the production of consistently palatable water, many communities are failing in their obligation to their consumers.

Algae are the most frequent cause of odors in water supplies, with decaying vegetation a close second. Trade wastes, although they occur less frequently, can be much more troublesome.

Algae types most frequently causing odor problems are *anabaena, aphanizomenon, asterionella, diatoma, dinobryon, synedra, synura* and *tabellaria.*

Chlorinous odors continue to be a serious issue, and return to the use of chloramines for improvement of water palatability appears to be a growing trend.

Greater importance of palatability is demonstrated by the wider adoption of the threshold dilution procedure for odor evaluation.

Preventive measures, except for control of algae with copper sulfate, are employed very infrequently.

Reports of completely successful corrective treatments show activated carbon far in the lead with an over-all effectiveness of 86%, compared with 25% for chlorine dioxide, 23% for super- and de-chlorination, 17% for free-residual chlorination, and 9% for aeration.

The proper point of carbon application, in relation to chlorine and pH-adjustment chemicals, is deserving of further attention in water-treatment practices.

From the viewpoint of public health and consumer relationship, water palatability has great significance, and the delivery of a consistently palatable water at all times should be the goal of all progressive individuals in the water-works profession.

AUTOMATION IN WATER-TREATMENT PLANTS

BY RAYMOND H. CONDELL*

[*Read November 20, 1958.*]

What is "Automation?"

Automation, as a word, is probably one of the most abused words in the English language today. Everything is automatic. Automation merely means to have some desirable event occur without human attention. It has been in existence for many years and touches all of us in our every-day life. Just about all our homes have a thermostatically controlled heating system. This is automation, since the temperature of our homes remains constant within acceptable limits without our attention.

What can automation do for you in a water-treatment plant?

As an operator it can reduce your menial manual tasks, thus giving you more time to spend in producing a higher quality, more uniform, less expensive product.

As a superintendent, it can, by freeing your operators of the menial tasks, increase your manpower for higher-level duties.

As a consulting engineer, it allows you to give your client, the consumer, a higher quality water at a lower cost per gallon.

Automation can be divided into two broad classifications:

1. Control;
2. Programming.

Control in the technical sense is the measuring of the value of some criterion, initiating the proper action to regulate a variable which maintains the value of the criterion constant within acceptable limits. Using the temperature of our homes as an example, the thermostat measures the temperature of the air, and when it is low, closes a switch which starts the oil burner. The oil burner heats the air, and when

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it is at the proper temperature, the thermostat opens the switch which stops the burner. This is automation!

Programming is the causing of an event or series of events to occur at the proper time and/or in the proper sequence to yield the desired results. Many of us have clock radios. With such a radio we pre-select the desired station and volume and the desired time of operation. As the pre-selected time arrives, the radio turns itself on and awakes us with soothing music, or more likely with a commercial. This is automation!

You can see from the foregoing that automation is not a strange new monster but is a wholly acceptable old friend.

In a water-treatment plant we can measure, record if desired, and control such criteria as levels, pressures, flows, pH, temperature, and chlorine residuals. We can also make the backwashing of the filters fully automatic.

The degree of automation to be installed in any water-treatment plant is a compromise among many factors. Among these factors are:

1. The cost and quality of available labor.
2. The cost and availability of chemicals.
3. The funds available to build and operate the plant.
4. The type and difficulty of the treatment problem.

The incentive to reduce the number of man-hours of labor naturally increases with the cost of the labor. Automation can do some jobs better than unskilled or semi-skilled operators. It would be very foolish to waste a highly skilled operator's time with the opening and closing of valves, when an automatic device could do it instead. Likewise, the incentive to reduce chemical consumption increases as the cost of chemicals goes up. It may be desirable to install automation if a small overtreatment or undertreatment by some reagent would cause undesirable results. Here we are depending on the automatic devices' controlling the reagent feed much more closely than a manual method. The automatic device is on duty every minute, and its attention is not distracted by outside influences. It, in giving its complete, undivided attention to the job at hand, does a better job than a

human operator. In broad terms the initial cost of a plant increases with the amount of automatic equipment installed, and the operating cost decreases. Obviously, if short-term economies are the goal, the plant is to be built with a minimum of automation. In general, unless overdone, automation will reduce operating costs and will eventually amortize itself and result in the consumer's paying less for his water.

Some treatment jobs may require so much of the operator's time in making tests to determine what is to be done and in performing the necessary operations that anything but an automatic device is unthinkable. On the other hand, the treatment may be an art and not a science, and only a human operator with a "feel" for the treatment process could perform the duty.

You have all seen a greater or lesser degree of automation in water plants. Even the simplest deep-well, standpipe plant usually has automatic pump control, maintaining the standpipe level between limits. The more sophisticated plants will tend more toward the epitome of automation, a completely automatic plant having no personnel at all.

One of the tasks which would otherwise consume valuable operator time is the gathering of data. Data records are necessary to evaluate past performance. You people know, far better than I, to what use these records are put. Other data are indicated only, and the indicated values are used to operate the plant. Again you are all acquainted with automatic recorders for flow level, pressure, etc. In the past these recorders have been of the circular chart or strip-chart types. A more recent innovation in data gathering has been a system which goes under the fancy name of data reduction or data logging. Data logging collects data, as did the older recorders, but does it on a log sheet, thus saving the operator the chore of reading his instruments every hour or other time period. The logger has the further advantage of taking a reading any time any of the critical values go outside preset limits. The logger usually prints out a tabulation on an automatic typewriter, and if any value is outside its limits, it prints these values in a different color from the standard so that these values stand out.

A data-reduction unit operates in a similar method but will correlate the data against itself or other fixed data. It may, for

example, measure the flow of chlorine, multiply this value by the cost of chlorine and divide the result by the water flow, thus "reading out" the cost of chlorination per unit of water. Thus the data-reduction unit may free the operator of the necessity of taking various readings and correlating them against standard data. The data-reduction unit and the logger may both read out on an automatic typewriter or may equally well read out on punch cards, punch tape or magnetic tape for use on modern business machines.

In programming, a program controller operating on time and/or other criteria will start and stop pumps or open and close valves. It may thus control levels in standpipes, clear wells or reservoirs or may control the washing of one or more filters.

In automatic control it is necessary to maintain the value of some criterion constant, this constant value yielding the desired results. It therefore follows that we must be able to measure this value or infer this value from other measurable values. It is further necessary that the variables affecting the measured value be controllable. For example, a venturi tube does not actually measure the flow of water but, in accelerating the water in its throat, produces a differential pressure between its throat and the upstream pipeline. The relationship between this differential pressure and actual flow rate has been thoroughly investigated and is thoroughly understood. We can therefore measure this differential pressure, and the instruments are calibrated in terms of flow rate. Likewise, we can position a gate valve, and the gate position will affect the resistance to the flow of water through the valve. By connecting the flow meter discussed above to the valve positioner by means of a controller, it is possible to maintain the flow rate at a pre-selected value. It is further possible to change this pre-selected value by means of a signal from some other measuring device, such as clear-well level controller. The device that measures the clear-well level would send its signal to the controller in such a manner that the flow rate would increase as the clear-well level fell. If the venturi meter and flow-control valve described above were on the effluent line from a filter, the filter flow rate would be controlled by the clear-well level, increasing as the level fell and decreasing as the level rose. Of course, it is possible to control the valve directly from the clear-

well level but, since a filter operates best when the flow through it is within definite limits, better results are achieved by means of the flow-control method. Since most plants would measure the filter flow regardless of the level control, the flow control adds little to the cost of the plant. The controller which is the same regardless of the process it is controlling actually solves a very complex mathematical equation, which involves such parameters as how far the measured value is from the desired point, how fast it is moving toward or away from the desired point, and what time lags are involved in the system. It is not necessary and is undesirable to get involved with the mathematics in this discussion. It is up to the plant designer and the instrument manufacturer to decide if the value of a given criterion can be controlled and if the correlation between the measurable values and the end results are known. They will select the proper equipment to do the job.

Water used by man, to serve him effectively as a means of accomplishing certain essential domestic, sanitary and industrial operations, is obtained from either surface or ground supplies. Each of these supplies can be considered as a major source of supply.

Surface-water supplies are those supplies obtained from rivers, lakes and streams. This water may contain mud, leaves, decayed vegetation, and human and animal refuse, which it picks up as it flows over the surface of the earth. This pick-up occurs as these substances are either dissolved upon contact with the water or are dispersed throughout the mass of the water by certain localized turbulent conditions, associated with its flow. Surface waters can be described as possessing some degree of turbidity and containing varying quantities of bacteria and dissolved organic and inorganic chemical compounds.

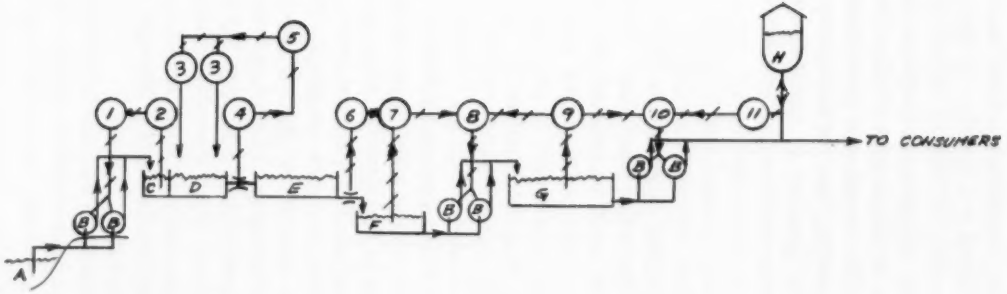
Ground-water supplies are those supplies obtained from either deep wells or springs. Since ground water is naturally filtered surface water, it is generally less turbid and contains fewer bacteria than surface water. However, it usually contains more dissolved calcium and magnesium compounds than surface waters in the same locality. In addition, iron, manganese and hydrogen sulfide are usually present in ground-water supplies of some regions.

It is evident that water obtained from either source of supply will contain either soluble or insoluble chemical compounds and will be contaminated to some degree with bacteria. When the presence of any of these substances is objectionable, the water must be treated to remove or reduce the objectionable substances, to obtain a water of acceptable quality for its end-use application.

A look into a hypothetical plant (Fig. 1) will illustrate the jobs being done by automation today. While possibly no plant exists which uses all of these automatic features, each feature is in use in one or more plants at this time. Since in general a surface-water treatment plant is more complicated than a ground-water plant, a surface supply will be assumed. All phases of the treatment which are sciences and can be controlled will be automated, while those phases of treatment which are arts or can not be controlled will be left to the skills of the operating staff.

The first-stage treatment, if it can be considered treatment, is the mechanical one of low-service pumping. The low-service pumps lift the surface water from the lake or stream into the coagulating and settling basins. The filters draw water from the settling basins as needed to maintain the clear well essentially full. This varying withdrawal would tend to change the level in the coagulating and settling basins if some control was not exercised. The low-service pumping station usually consists of a multiplicity of pumps for the sake of reliability. The pumps may be of the same or of different capacities. The pumps would be started and stopped by an automatic controller. The level in the coagulation basin could be measured by means of a bubbler, wherein air is blown through a dip tube installed in the coagulating basin. The air pressure in the dip tube is a function of the depth of submergence of the end of the dip tube. Since the dip tube is installed in a fixed position, the air pressure is a measure of the basin level. The air pressure is applied to a multiple-contact pressure switch. The switch contacts, through motor starters, will start the pumps as the level falls and stop the pumps as the level rises. The pumps start and stop in a sequence that is selected by the operator by means of transfer plugs. The sequence of pump operation is usually automatically alternated

A. LAKE OR STREAM
B. PUMPS
C. COAGULATING BASIN
D. SETTLING BASIN
E. FILTERS
F. CLEARWELL
G. RESERVOIR
H. ELEVATED STORAGE



1. PUMP CONTROLLER
2. LEVEL METER
3. CHEMICAL FEEDERS
4. FLOW METER
5. FEEDER CONTROLLER
6. FLOW METER
7. LEVEL METER
8. PUMP CONTROLLER
9. LEVEL METER
10. PUMP CONTROLLER
11. LEVEL METER

FLOW LINES
MEASUREMENT AND CONTROL LINES

FIG. 1.—TYPICAL WATER-TREATMENT PLANT.

by the pump controller, to equalize the wear on each pump and to prevent any pump from deteriorating from lack of use. In this and in all automatic control it is possible for the operator to take over and control manually, in case of failure of the automatic equipment, or to handle any unusual problems that may arise in the plant. It may also be desirable to totalize the operating time of each pump, so that the operator or maintenance man can tell at a glance the total running time for each pump. With such an automatic control it is possible to maintain the level of the coagulating basin constant within as close limits as desired. The usual limits are three or four inches.

The total water flow through the plant can be measured in either of two ways. First and usual method is to install a meter in the line from the settling basin to the filters. The meter, of course, should carry the entire plant flow. Second, the flow at the effluent of all filters could be summed and this sum used as total plant flow. If it is assumed that total plant flow is known, it is possible to use this flow signal to pace the various reagent feeders to feed alum, lime and carbon to the coagulating or settling basin, to achieve the required end results. As the application of these reagents is more of an art than a science, it is not possible to control the feed automatically and is only possible to feed them in proportion to the water flow. It will be necessary for the operator manually to adjust the proportion or dosage as required by the water passing through the plant. For example—consider the feed of alum or other coagulant. The final control criterion would be the size of the floc or the turbidity of the water leaving the settling basin. The water remains in the settling basin for approximately one hour, and any detected change in the turbidity would call for a corrective change in the coagulant feed one hour previously. This is far beyond the capabilities of the usual automatic controller. This type of operation is best left to a skilled operator.

One reagent feed that can be placed under automatic control is the soda-ash feed for pH correction. pH can be measured and the feed of soda ash continuously and automatically controlled to hold a constant pH value. Here the controller measures the pH electro-chemically and regulates the feed of soda ash by means of a pneumatic controller. It is not the intent of this

paper to discuss the operation of a controller, but the following description of terms may prove useful.

Proportional Band. Usually adjustable.

Assume a controller positioning a flow-control valve. The proportional band is the distance (usually expressed in percent of indicating-scale travel) which the indicator must move to stroke the valve from full closed to full open. Thus a 100% proportional band means the indicating pointer must move over its entire range to stroke the valve from full open to full closed.

Set Point.

The desired value of the criterion which is to be maintained. The set point is usually manually adjustable, though it may be automatically set by some other criterion.

Offset.

For each installation there is a given value of proportional band which will give optimum control. If the proportional band is set greater than this value, slow, sluggish action will result. If the proportional band is set less than this value, "hunting" will ensue, wherein the controller will close the valve too far, causing the value of the criterion to "overshoot" or go beyond the set point, and then open the valve too far, causing an "overshoot" in the opposite direction. This continuous hunting is, of course, not good control. In start-up practice the proportional band is purposely first set too narrow (too low of a percentage), causing hunting. The proportional band is slowly widened until the hunting just stops. Assume this value turned out to be 100%; a change in water flow may call for the valve to change its position by 10%. The only way the valve can move 10% is for the pointer to move 10%; this represents a change of 10% of scale of the criterion and is, of course, not good control. This 10% change in pointer position is known as "offset." Something is needed to return the pointer to the set point by breaking the "locked in" relationship between valve and pointer. This something is Automatic Reset.

Automatic Reset.

Automatic reset is a feature, built in the controller, to overcome offset. It detects the amount of offset, as the controller tends to reach equilibrium at its new value, and slowly applies a corrective effort to position the valve at a position which will return the pointer to the set point. Reset tends to make the controller slightly less stable and may require widening the proportional band a bit.

Derivative Response.

Derivative response is a third feature, built into the controller, to overcome time lags between the action, such as valve positioning, and the measured results. Any given controller application will require adjustable proportional band and may require either reset or derivative response, or both. Here it is up to the plant designer with a thorough knowledge of the process to select the proper instrument.

Another reagent feed that can be placed under automatic control is the prechlorination feed. Here it is usually desirable to maintain a fixed chlorine residual, regardless of fluctuations in water flow rate or changes in the chlorine demand of the water. Chlorine residual can be measured electrochemically or photometrically and the chlorine-residual signal applied, by means of a controller, to the chlorinator. Since there is a considerable time lag between the injection of chlorine into the water and the measured results, better control will be achieved by pacing the chlorinator from water flow, wherein the chlorine flow is proportional to the water flow, and having the chlorine-residual controller change the dosage as required to maintain a constant residual.

All of the items discussed so far—pump operation, reagent feed and level—can be recorded by conventional means or the more sophisticated data loggers or data-reduction units.

Water flow rate, in the past, has been measured almost exclusively by means of a differential-pressure producer, such as the venturi meter or orifice plate. The venturi has been far and away the most popular in all but the smallest plants. A more recent innovation, and one growing in popularity, has been the

magnetic meter. In the differential pressure producer the head loss varies as the square of the flow. This represents a power consumption if the water is being pumped through the meter. In some gravity-flow installations the limited gravity head limits the metering differential to a value too low to give a wide, measurable flow range. The meter is also exacting in its upstream and downstream piping configurations.

The magnetic meter is truly obstructionless, since its ID is straight and of the same diameter as the pipe. Its pressure loss is exactly the same as a piece of pipe of the same length. The magnetic meter consists of a length of non-electrical-conducting, non-magnetic pipe with two electrodes installed diametrically opposite each other. A pair of coils is installed on opposite sides of the pipe. Electric current is passed through the coils, creating a magnetic field through which the water flows. The water, being electrically conductive, acts as a conductor in a generator with its length equal to the pipe diameter. As in a generator, the potential generated is dependent on the strength of the magnetic field, the length of the conductor and the velocity of the conductor. Since the magnetic field is constant and the length is constant, the potential varies directly as the velocity. Our conductor in the magnetic meter (the water) is non-rigid, and we measure the true average velocity of the water. By measuring the true average velocity we are freed of any upstream or downstream piping configurations. The potential generated across the electrodes of the magnetic meter is measured by a self-balancing potentiometer. The potentiometer, of course, can indicate/record/or control the flow rate.

If this meter were between the settling basin and the filters, it would be possible for its flow signal to control the reagent feeds in proportion to the water flow rate.

On the filters themselves loss-of-head meters would be found, measuring the pressure loss through the filters (see Fig. 2). Since the head loss through a filter is dependent on the cleanliness of the filter medium, the loss-of-head meter can not be used for control but can only be used to sound an alarm on excessive loss of head, indicating that the filter requires washing.

The filter operates at its peak efficiency when the flow rate through the filter is maintained within limits. For this reason it

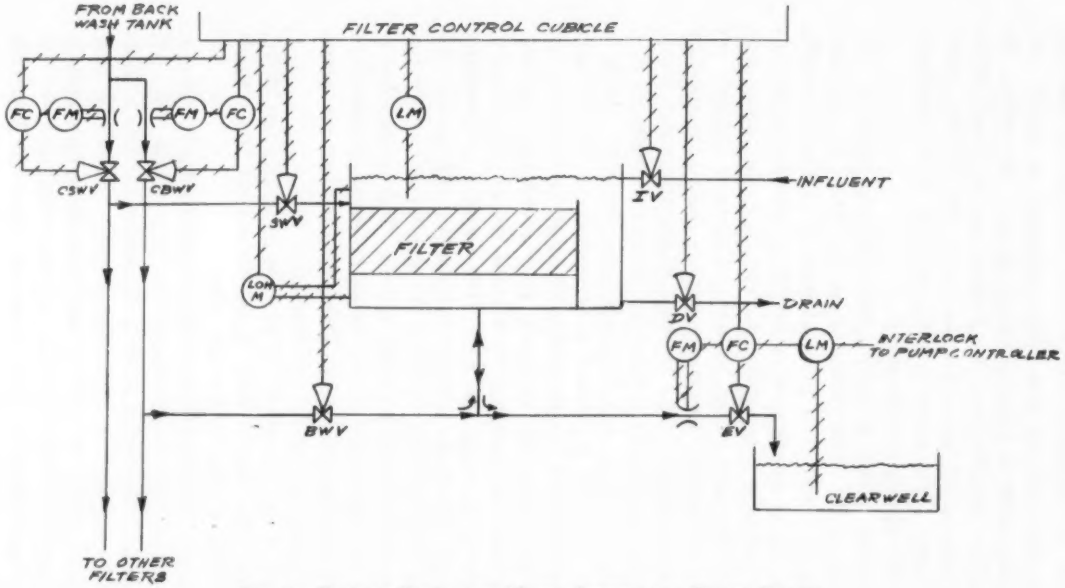


FIG. 2.—TYPICAL VALVE AND METER SYSTEM FOR WATER FILTER.

BWV	Back-Wash Valve	*FM*	Flow Meter
CBWV	Common Back-Wash Valve	*IV*	Influent Valve
CSWV	Common Surface-Wash Valve	*LM*	Level Meter
EV	Effluent Valve	*LOHM*	Loss-of-Head Meter
FC	Flow Controller	*SWV*	Surface-Wash Valve

is desirable to have the filter-effluent flow rate under automatic control. The set point of the filter-effluent flow rate may be automatically set by a level controller in the clear well so that the filters operate at a rate equal to the demand on the clear well. It would be well to have alarms on the flow-rate measuring instrument to indicate excessive or insufficient flow rate through the filter.

These alarms could automatically cut additional filters into the line when the flow through the filters in service became excessive, or automatically remove filters from service when the flow rate dropped too low. This would be possibly carrying automation to the extreme.

Water normally flows from the clear well to the reservoir by gravity or by low-service pumps. If by low-service pumps, the pumps can be controlled as described above with the extra feature of interlocks on the clear-well level meter, to prevent the pumps from attempting to pump from an empty clear well.

Back-washing of the filters is usually done with water under gravity flow from an elevated back-wash storage tank. Again a group of back-wash pumps, under automatic control from level in the back-wash tank, pumps water from the clear well or reservoir to the tank. Interlocks again would make sure that these pumps operated only at the proper times.

And so it would be with the high-service pumps, pumping from the reservoir to the consumer. These would be operated from the level in elevated tanks, if any, or from pressure in the mains. If the high-service pumps were remote from the plant, they could be operated by remote control from the plant over leased or private wires. Flow, pressure and level data from remote reservoirs, booster stations, or pressure taps could be telemetered into the plant by means of the same wires, or the pumps could be controlled and the data returned to the plant by means of radio signals.

The final chlorination, or postchlorination, can also be controlled as described under prechlorination above.

The reagents are stored in containers suitable for the type of material, and the inventory is kept by means of weight or level. These signals in at least one plant are fed to a data-reduction system, which keeps a perpetual inventory of the chemicals.

Once a day the inventories are automatically checked against the minimum stock requirements and purchasing lead time, and the read-out system indicates which chemicals need reordering. In this same plant all chemical, power and labor charges are correlated with water flow, and a log sheet is kept of all costs per million gallons of water.

We have been talking primarily of control and ignoring programming. The automatic pump operation described above, which possibly could be considered programming, is actually control, since the pumps were started and stopped to maintain constant level or pressure. In true programming the sequence of events is an end in itself. Filter back-washing is an example of pure programming.

In our hypothetical plant, consider eight filters. Each filter has a non-throttling influent valve, a throttling effluent valve, a non-throttling drain valve, a non-throttling surface-wash valve and a non-throttling back-wash valve. The throttling effluent valve is operated by the filter-effluent flow controller. In addition to the above five valves for each filter, there are one common surface-wash flow meter and flow-control valve and one common back-wash flow meter and flow-control valve. The surface-wash and back-wash valves on each filter are of lighter construction than the common surface- and back-wash valves and are so interlocked that they must be open before their respective common flow-control valves are open and must close after their respective common flow-control valves are closed. All valves are of the butterfly type and are pneumatically operated by electric signals through solenoid pilot valves.

The eight filters are arranged in two rows of four each, and only the filter at one end of each row has an effluent flow meter of the magnetic type. The other filter effluents are not metered. It has been proven by field tests in this plant that the flow rate through all filters averages equal enough for practical purposes. This is true only with magnetic meters, with their pressure loss equal to an equivalent length of pipe. The flow signal from each of the magnetic meters is multiplied by the number of filters in operation in each row. If either of the filters with the effluent meter is out of operation, the flow signal from the remaining meter is multiplied by the number of filters in operation in both

rows. The operator, in placing a filter in or out of operation, does so by means of a multiple-position manual switch, and this switching changes the flow-signal multiplier automatically.

There is a filter-operating unit at each filter. The six filters without effluent meters have small units containing only the manual multiple-position switch and two lights for each valve, indicating the valve is either open or closed. The two filters with effluent meters have full operating consoles. The consoles contain switches and lights similar to the smaller units. In addition, the consoles also contain the total effluent-flow rate, surface-wash flow rate, back-wash flow rate and loss-of-head meter and alarm light for loss of head. The manual set point for the surface-wash flow-rate controller and back-wash flow-rate controller is also on the two consoles.

The multiple-position switches are so located that the operator can see the filter during manual washing. Each switch has nine positions which operate valves in the following manner:

Auto: Filter follows automatic washing controller described below.

Filter: Influent valve open, effluent valve under automatic control (set by clear-well level); all other valves closed.

Drawn Down: Effluent valve under automatic flow control; all other valves closed.

Drain: Drain valve open; all other valves closed.

Surface Wash: Drain valve open, surface wash open, common surface-wash valve under flow control; all other valves closed. Interlock prevents common surface-wash valve from opening until surface-wash valve is open.

Surface and Back Wash: Drain valve open, surface-wash valve open, common surface-wash valve under flow control; back-wash valve open, common back-wash valve under flow control. Interlock prevents common back-wash valve from opening until back-wash valve is open. All other valves are closed.

Back Wash: Drain valve open, back-wash valve open, common back-wash valve under flow control. All other valves closed. Interlock prevents surface-wash valve from closing until common surface-wash valve is closed.

Fill and Stand-by: Influent valve open, all other valves closed. Interlock prevents back-wash valve from closing until common back-wash valve is closed.

Off: All valves closed.

Switch has now rotated 320 degrees; next position is "auto."

For automatic operation each filter has a level meter of the bubbler type, while only the filters with effluent meters have the loss-of-head meters. If we assign arbitrary numbers to the filters, filters 1 and 8 have the effluent meters, and the washing order will be 1, 2, 3, 4, 5, 6, 7, 8. Only those filters whose operation-selector switch is in the "auto" position will be washed. Filters whose switches are in the "off," "stand-by" or "filter" positions will be eliminated from the sequence and will consume no time. The next filter in the sequence whose switch is in "auto" will be washed immediately after the preceding "auto" filter. If any switch is not in the "auto," "off," "stand-by" or "filter" position, the automatic washing of the entire filter bank will not start until the switch is placed in one of these four positions. Obviously, either filter #1 or filter #8 or both must be in operation at all times, or there would be no flow metering or loss-of-head metering. Filters are placed in or out of operation manually to match the plant load.

With all filters on the line, filtration will continue at a rate under clear-well-level control with all eight effluent flow-control valves receiving the same positioning signal from the two flow controllers (four valves from each controller). Should the flow rate drop too low for good filter operation, the low flow-rate signal will sound, warning the operator who will remove one or more filters from the line. Upon excessive loss of head an alarm will sound, warning the operator of the condition. At a time compatible with the plant operation, he will manually initiate the automatic back-washing by pressing a button on the control cubicle. The control cubicle is located in the control room.

Upon the push-button signal the first filter is washed as follows: Push button closes influent valve. Effluent valve remains under flow control. As filter level draws down to a predetermined level the effluent valve closes. Closed effluent valve opens drain valve and opens surface-wash valve. Open drain

valve, interlocked through open surface-wash valve, opens common surface-wash valve. Common surface-wash valve controls the surface-wash flow rate. Timer A-1 closes common surface-wash valve, opens back-wash valve and sends start signal to second filter. Closed common surface-wash valve closes surface-wash valve. Open back-wash valve opens common back-wash valve. Common back-wash valve controls the back-wash flow rate. Timer B-1 closes common back-wash valve. Closed common back-wash valve closes drain valve and closes back-wash valve. Closed drain valve opens influent valve. Level signal from filled filter opens effluent valve, which will be under automatic flow control. Filter #1 is now back on the line.

The signal from timer A-1, which closed the common surface-wash valve at the end of surface wash on filter #1, closes the influent valve on filter #2. Falling level in filter #2 closes the effluent valve, and the sequence of operation described for filter #1 repeats itself for filter #2, and so on for each filter in turn until all have been washed and returned to the line.

Note that the draw-down for the filter #2 starts as #1 completes its surface wash, and the draw-down for filter #3 starts as #2 completes its surface wash. The result of this sequencing is that several filters are in various stages of washing concurrently. If average times are assigned to draw-down, surface washing, back-washing and fill time, each filter is off the line for 34 min. Each filter follows the preceding filter by 19 min. The result is a loss in plant capacity equal to the capacity of 1.8 filters. The total washing time for the entire eight filters is approximately 167 minutes. Losing 1.8 filters' capacity for 167 minutes is equivalent to losing the capacity of all filters for 38 minutes. Thus this control system washes all eight filters in a minimum elapsed total time and requires only enough back-wash capacity for one filter at a time, giving resulting economies in back-wash storage-tank capacity, back-wash pumping rate and loss of production during washing.

Thus we have considered automation in water plants from both the control and programming viewpoints. The actual amount of automatic equipment to be placed in any given plant is a mutual decision of the designer and the client, as they weigh the desired results against the capital investment and operating costs.

THE BREAK-POINT PROCESS FOR FREE RESIDUAL CHLORINATION

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I. INTRODUCTION

Chlorination is the act of applying chlorine to water or to water-borne wastes. When it is necessary to produce residual chlorine, one of two types of chlorination is used: namely, Free Residual Chlorination or Combined Residual Chlorination. These are descriptive terms related to the type of residual chlorine produced when chlorine is applied. Thus, *Free Residual Chlorination* is the addition of enough chlorine to produce and maintain free available residual chlorine, and *Combined Residual Chlorination* is the addition of the proper amount of chlorine to produce and maintain combined available residual chlorine (chloramines).

The *Break-Point Process of Chlorination* is chlorination of water or waste containing ammonia in accordance with a plan that will insure the production of free available residual chlorine. When ammonia is absent such planning is unnecessary, because the residual chlorine produced, following the application of chlorine to such a water, will be in the form of free available chlorine. The residuals produced by the Break-Point Process are sometimes known as Break-Point residuals—another name for free available residual chlorine.

Free residual chlorination has been widely accepted because this type of residual kills practically all bacteria within a few minutes, whereas equivalent amounts of combined available residual chlorine may require one and one-half or more hours to accomplish the same result. This characteristic alone usually justifies the use of this type of chlorination. In addition, it can be used advantageously for algal and slime control; for taste and odor control; as a coagulant aid; for the oxidation of iron and

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manganese; to bleach color; to oxidize ammonia; and to destroy hydrogen sulfide. Furthermore, the maintenance of free available residual chlorine within the distribution system will preserve the water quality, will check the growth of slime organisms, will minimize corrosion attributable to biological growths, and will minimize "red" and "black" water difficulties.

Combined residual chlorination, although acceptable as a type of chlorination, is less widely used than free residual chlorination because of its limited ability, at the levels ordinarily carried, to control algal growths or to kill certain non-pathogenic organisms that produce slime. It is, however, effective, within limits, for the killing of pathogens and for the oxidation of H_2S and Fe. Another function is the control of tastes and odors (21), (29).

II. Role of Ammonia

Inasmuch as practically all surface waters and most ground waters contain some ammonia, it is good practice to utilize the principles of Break-Point Chlorination to insure the production of free available residual chlorine.

The form and amount of nitrogen in water to be chlorinated should be known if chlorination is to be completely successful. The only forms that need be considered are ammonia nitrogen (NH_3—N) and albuminoid nitrogen. Chlorine will either combine with ammonia nitrogen to form chloramines or will oxidize it, if enough is used, to inert nitrogen gas (N_2) and a small amount of nitrous oxide (N_2O). Chlorine combines with albuminoid ammonia to form organic chloramines which, as a group, are generally considered to be of little value in water treatment. Albuminoid nitrogen, in contrast to ammonia nitrogen, is not readily oxidized by chlorine, so that usually no attempt is made to remove it by chlorination. If a water being chlorinated contains neither ammonia nitrogen nor albuminoid nitrogen, any residual produced will be in the form of free available chlorine. If ammonia nitrogen is present, then it will be necessary to use the Break-Point Process to obtain free available residual chlorine.

The wide use of the Break-Point Process stems from the fact that in the majority of waters the amount of ammonia

nitrogen is greatly in excess of albuminoid ammonia, and use of the process makes free residual chlorination practical.

To produce residual chlorine composed wholly, or almost so, of free available chlorine via the Break-Point Process, the chlorine applied must be sufficient to satisfy the immediate chlorine demand plus at least ten times the ammonia nitrogen content. When this amount of chlorine is added, the ammonia nitrogen will be destroyed, and the residual chlorine remaining will be composed wholly, or almost so, of free available chlorine. The small amount of combined residual remaining will be organic chloramines.

TABLE 1.—CONDITIONS FAVORABLE TO BREAK-POINT CHLORINATION

Optimum pH	— 7.5
pH Range	— 6.5-8.5
Time of Reaction	— approximately 30 minutes at pH 7.5
Dosage ratio of chlorine to N:	
10:1	minimum for ammonia nitrogen in water
25:1	for highly polluted waters
15:1	average

The typical Break-Point residual chlorine pattern is shown in Fig. 1. This same figure also shows that the amount of ammonia, natural or added, in water under treatment governs the extent or magnitude of the "hump" and "break" areas.

The shape of these curves is governed by the type of ammonia present. A preponderance of ammonia nitrogen tends to produce a high "hump" and sharp "break," whereas a preponderance of albuminoid nitrogen will tend to smooth out both the "hump" and "break," leaving in some cases little more than a waver in the residual curve. Approximately 0.05 ppm ammonia nitrogen is the smallest amount that will produce a characteristic break-point curve. The residual within the "hump" area consists of combined available chlorine, whereas the residual beyond the "break" consists essentially of free available chlorine.

Fig. 2, Curve A, shows the shape of the curve to be expected from the addition of chlorine to ammonia-free and organic-free water; Curve B shows what happens to the curve when free ammonia is present; and Curve C shows the influence of albuminoid nitrogen (6), (11), (20).

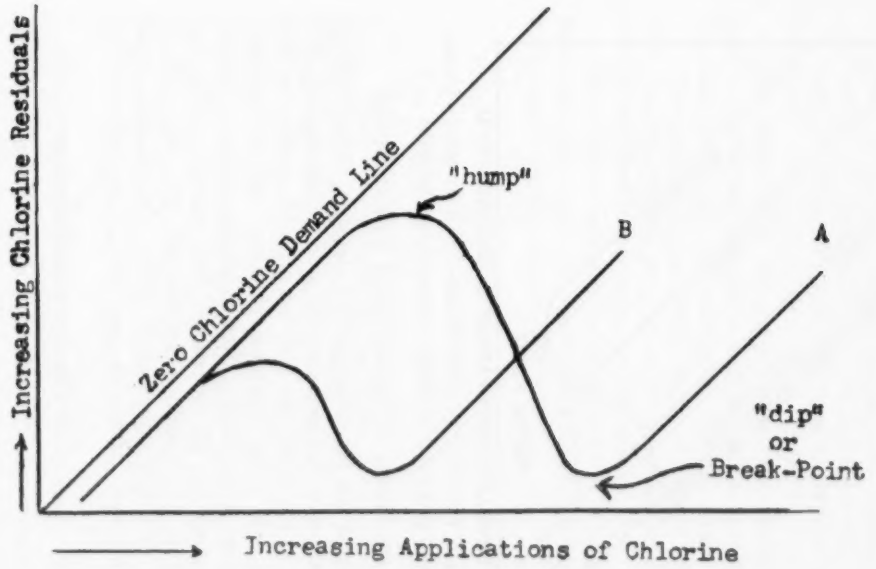

FIG. 1.

In Fig. 1, the ammonia content of the water, other conditions remaining the same, is twice as great for Curve A as for Curve B. This shows that as the ammonia content is increased, the residual chlorine at the top of the "hump" increases, and the amount of chlorine required to reach the "break-point" also increases in proportion to the increase in ammonia content.

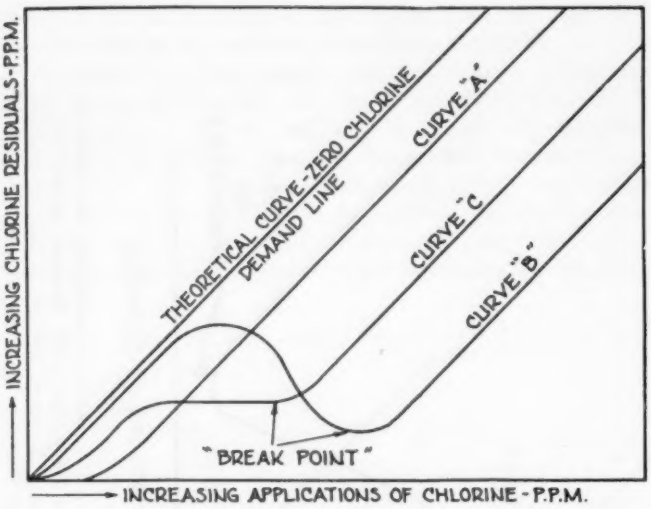

FIG. 2.—TYPICAL CHLORINE RESIDUAL CURVES OBTAINED WHEN WATER IS TREATED WITH INCREASING AMOUNTS OF CHLORINE.

III. REACTIONS IN BREAK-POINT CHLORINATION

The Break-Point reactions proceed stepwise. When chlorine is added in excess of that necessary to produce chloramines with the ammonia in the water, the reaction proceeds rapidly to form hypochlorous acid (free available chlorine) and chloramines. The chloramines, immediately after formation, begin to decompose in the presence of the excess free chlorine. The end products of this decomposition are nitrogen gas (N_2), nitrous oxide (N_2O), and hydrochloric acid (HCl). Occasionally, small amounts of nitrogen trichloride gas (NCl_3) are formed (20) (36).

IV. POINTS OF CHLORINE APPLICATION

In a treatment plant employing coagulation and settling, chlorine should be applied prior to all other chemicals wherever possible. This is to allow the longest possible retention time for completion of the break-point reactions, to satisfy insofar as possible the organic chlorine demand of the water, and to provide a deep area of defense for the total killing of bacteria.

The application of chlorine ahead of aeration is good practice. This affords a point of release for some of the volatile chlorinated organic compounds responsible for chlorinous tastes and odors in water, including nitrogen trichloride. Some of the chloramines will be lost by aeration, but there will be no loss of free available chlorine. This is because hypochlorous acid is not volatile.

The Break-Point Process is seldom used where the chlorine must be added directly into a pipeline unless contact with air is provided later, such as in an aerator or open basin.

Chlorination at the plant intake or source of supply will maintain the carrying capacity of the intake main (See V, 10) as well as provide the maximum contact time.

Protection of open reservoirs may be accomplished by Free Residual Chlorination, applied either at the inlet of the reservoir or in a recirculation system (See V, 3).

V. Chlorine Requirements for Benefits of Free Residual Chlorination

The amount of chlorine required to produce free available residual chlorine when ammonia is present depends, among other things, upon the character of the water, the time of contact, the temperature, the exposure to sunlight, and the magnitude of the residual desired at any given point in the system. Free available residual chlorine can be produced in unpolluted waters, devoid of ammonia, organic matter, hydrogen sulfide, or other reducing material, with chlorine applications of 1.0 ppm or less. Grossly polluted waters, where the Break-Point Process must be used, may require chlorine applications as great as 20.0 ppm or more. The average application for moderately polluted waters is usually less than 7.0 ppm (6), (11), (20).

1. Bacterial Control

Under favorable conditions bacteria grow and reproduce with amazing rapidity. When growing at their maximum rate the generation time is about 20 minutes. Water, relatively free of pollution, is not an especially favorable environment for rapid

Note: The application of chlorine to water for any purpose will consume alkalinity. To maintain the original alkalinity, lime, caustic soda, or soda ash should be added at the rate of approximately 1.2 ppm alkalinity as calcium carbonate for each ppm of chlorine added.

bacterial growth, but when it is warmed, as in a swimming pool, or loaded with organic waste, the conditions for rapid bacterial growth are improved. If allowed to grow uncontrolled, even for short periods of time, disaster can follow. For instance, if typhoid or other water-borne pathogenic organisms should be present, a lapse in chlorination could result in an epidemic. Should excessive numbers of slime-producing organisms pass into a manufacturing process, expensive shut-downs could ensue.

The rate of bacterial kill by chlorination is influenced by factors such as (1) pH; (2) temperature; (3) time of contact; (4) residual chlorine type; and (5) residual chlorine concentration.

At pH values around 5.0-6.0 the bacterial killing rate is much more rapid than at pH values in the range of 9.0-10.0.

The effectiveness of chlorination varies directly with the temperature. Furthermore, bacteria do not always die instantly when treated with chlorine. Time must be allowed for chlorine to penetrate the protective coating or to act on the enzymes upon which bacteria depend for survival.

The time of contact required by various regulatory officials varies from 15 to 40 min. or more, depending upon local conditions. In any event, the greater the time of contact the more complete will be the kill. Free available residual chlorine kills practically all types of pathogenic bacteria within a three- to four-minute period, whereas the same concentration of combined available residual chlorine would require as much as 90 min. or more.

Suggested minimum free residual chlorine for plant operation is:

pH 6-8	0.2 ppm
pH 8-9	0.4 ppm
pH 9-10	0.8 ppm

These minimums are usually adequate to obtain disinfection with a ten-minute contact time at the temperatures normally encountered (4), 10), (29), (33), (35), (39), (40).

2. Taste and Odor Control

Free residual chlorination is effective in controlling tastes and odors found in natural and waste-contaminated waters. It

accomplishes this primarily through the oxidation of the compounds responsible.

Tastes and odors in water are caused by infinite varieties and combinations of different sources; thus it is very difficult to indicate a treatment process which will give guaranteed results.

The most frequently encountered tastes and odors, on the basis of their probable source, may be assigned to one of these categories:

(a) Aquatic growths, such as algae and diatoms, and other organic matter.

(b) Inorganic compounds found in natural water supplies, such as hydrogen sulfide and sulfates.

(c) Contamination by wastes such as sulfites and phenols.

The first two categories will usually respond to Free Residual Chlorination with residual concentrations about equivalent to those used for bacterial control; *i.e.*, 0.2-0.8 ppm, although the chlorine requirements to reach these residuals may be considerably greater. Time is an important factor in treating aquatic growths with chlorine. After some of these forms have been killed with chlorine, an oil is released which is responsible for the taste and odor. This oil must be oxidized by chlorine. Sometimes this is a slow process, often requiring as much as four hours.

Although most of the tastes and odors referred to in (c) may be adequately removed by Free Residual Chlorination, some are notably resistant to such treatment. Phenols and phenolic compounds are prime examples. For these and other difficult cases from any of the sources above, one of the following should be used:

(a) Break-Point Process to a high free residual, followed by dechlorination.

(b) Break-Point Process in conjunction with activated carbon.

(c) Break-Point Process followed by chlorine dioxide. This treatment is specific for phenolic tastes and odors.

When treating water for tastes and odors, chlorine doses below those required for break-point may intensify rather than

eliminate them. Careful attention to clarification prior to filtration will remove much of the matter causing tastes and odors.

Protection of the water in the distribution system must not be neglected, and consideration should be given to rechlorination if residuals tend to drop off in the system or in balancing reservoirs.

pH and temperature are usually not critical in taste and odor control within the limits normally encountered in waterworks practice. An exception to this is sometimes encountered in lime softening, where the high pH may tend to make taste and odor control more difficult. In such cases, chlorination should precede the addition of lime, far enough in advance to allow sufficient contact and where the pH is most likely to be within the optimum range.

Time is an important element in taste and odor control. It has been previously pointed out that as much as four hours or more of contact time may be required.

The addition of sufficient chlorine to produce a safe residual of 0.2 to 0.8 ppm is usually satisfactory, except in the case of chlorination to very high residuals, sometimes known as super-chlorination. The amount will have to be determined by trial. The amount of ammonia, activated carbon, or chlorine dioxide will also have to be determined by trial (5), (7), (8), (9), (13), (18), (24), (25), (29).

3. Algae Control

Open clear- or filtered-water reservoirs, subject to algae growths, can be protected by maintaining free available residual chlorine of not less than 0.5 ppm. Since sunlight tends to decompose residual chlorine, the most practical means to accomplish this is to set up a chlorinating station at the reservoir and control it by a flow-control device or provide a recirculating system similar to that used in a swimming pool. In this system a residual recorder may be used to monitor the chlorine application, because sunlight and temperature variations may require frequent chlorine-feed adjustments.

Contact time is normally sufficient in a reservoir for completion of the chemical reactions involved (19), (29).

4. Hydrogen Sulfide Removal

Chlorine quickly reacts with hydrogen sulfide, converting it to sulfur (S) or to sulfate, depending upon the amount of chlorine applied.

(a) Conversion of H_2S to S by chlorination:

(1.) $H_2S + Cl_2 \rightarrow 2HCl + S$
pH—optimum pH 5.0, range pH 5-9
Temperature—not an appreciable factor
Time—rapid at pH 5.0, slower as pH increases
Chlorine required—2.1 ppm for each 1 ppm H_2S

The precipitated sulfur can be removed by filtration. (The presence of free sulfur is indicated by a cloudiness in the water and demonstrates an absence of free available chlorine.)

(b) Conversion to sulfates:

(2.) $H_2S + 4Cl_2 + 4H_2O \rightarrow 8HCl + H_2SO_4$
pH—optimum pH 9.0, range pH 6.5-9
Temperature—not an appreciable factor
Time—rapid at pH 9.0, slower as pH decreases
Chlorine required—8.5 ppm for each 1 ppm H_2S

The sulfates formed are soluble and do not produce a haze in the water. The presence of free available residuals will indicate that all of the sulfides have been converted to sulfates.

Aeration prior to chlorination will remove a portion of the sulfides (31), (33), (34).

5. Color Removal

True color in waters, where turbidity removal is not a factor, many times can be removed by free residual chlorination without any other treatment except, perhaps, filtration and/or pH control. The pH must be kept on the acid side, and the most effective pH range is between 4.0 and 6.8. Most highly colored, low-turbidity waters are either naturally acid or so lightly buffered that chlorine alone may be sufficient to reduce the pH. Care must be taken, when decolorizing with chlorine alone, that readjustment of the pH upward for corrosion control does not result in color return.

Temperature and time are not important factors in color

removal, but adequate mixing is. There is no rule to determine the amount of chlorine required, except that when a free residual is obtained, maximum color removal is achieved. The per cent color removed will vary.

Where color is accompanied by turbidity and coagulation is practiced, prechlorination to a free residual will aid materially in color removal by two means. The first is through oxidation of part of the color and the second is through its action as a coagulant aid (see next paragraph). Thus, two benefits may be expected: better color reduction, decreased coagulant dosage. The chlorine dose is only that amount necessary to effect maximum color reduction. Time, temperature, pH, and alkalinity needs are determined by the coagulation requirements (5), (7), (24).

6. Aid to Coagulation

Prechlorination to a free residual is nearly always effective in improving coagulation or reducing the coagulant dose, or both. It is not clearly understood how chlorine acts as a coagulant aid, although it is probably due to the oxidizing effect on organic matter.

Chlorine is used in the preparation of chlorinated copperas, a coagulant, and activated silica, a coagulant aid. In the latter case, all the chlorine used is available for other purposes, because none of the oxidizing capacity is lost (13), (29), (31).

7. Iron Removal

Chlorine will oxidize ferrous iron according to the equation:

(3.) $2Fe(HCO_3)_2 + Cl_2 + Ca(HCO_3)_2 \rightarrow 2Fe(OH)_3 + CaCl_2 + 6CO_2$

The soluble ferrous bicarbonate, $Fe(HCO_3)_2$, is oxidized by chlorine to the insoluble ferric hydroxide, $Fe(OH)_3$, which can be settled out or removed by filtration.

pH—optimum pH 7.0 and above, range pH 4-10

Temperature—the reactions are relatively slow in cold water

Time—maximum 1 hour, faster at optimum pH

Chlorine required—0.64 ppm for each part of iron as Fe

Alkalinity—reaction requires 0.9 ppm alkalinity as calcium carbonate ($CaCO_3$) for each ppm iron as Fe

Iron can be oxidized by either free or combined chlorine. If the iron occurs as complex organic compounds, the use of free residual chlorine is recommended.

Pre-aeration will oxidize some iron and will reduce the carbon dioxide content. This tends to increase the pH to a level where chlorine will be more effective. Frequently, lime can be used to remove the remaining CO_2 and to raise the pH further (5), (14), (16), (31).

8. Manganese Removal

Chlorine will oxidize manganous manganese to insoluble manganese dioxide (MnO_2):

(4.) $Cl_2 + MnSO_4 + 4NaOH \rightarrow MnO_2 + 2NaCl + Na_2SO_4 + 2H_2O$

The manganese dioxide produced may be removed by filtration. The dark deposits of manganese dioxide, which plate-out on the sand grains, act as a catalyst and make possible the complete extraction of manganese from water.

pH—optimum pH 7.0, range pH 7-10

Temperature—not an appreciable factor

Time—2 to 3 hours at pH 7.0, less as pH and chlorine residuals are increased

Chlorine required—1.3 ppm for each part of manganese as Mn, exclusive of the requirements for iron, ammonia, hydrogen sulfide, etc. The chlorine *must* be in the form of free available chlorine.

Alkalinity—reaction requires 3.4 ppm alkalinity as calcium carbonate ($CaCO_3$) for each part of manganese as Mn (5), (14), (16), (31).

9. Maintaining Filter Runs

The majority of water treatment plants where filtration is employed use chlorine as a pre-treatment and, consequently, are usually not troubled with filters clogged with algae and slime.

If unchlorinated water passes into either pressure or rapid sand filters for any length of time, bacteria are almost sure of gaining a foothold.

If prechlorination is not employed, the organic growths in and on the filter beds will greatly reduce the capacity and length of filter runs. Rapid-sand roughing filters are quite susceptible to this difficulty. The maintenance of residual chlorine in the filter effluent by application of chlorine as far as possible ahead of the filters will prevent reduced filter runs, caused by bacterial slimes and algae growing in the beds. In addition, since the chlorine requirement has been satisfied, the post-chlorination dosage rate will be reduced and easier to maintain.

Careful control of chlorination by gradual increases of dosage until the break-point is reached can be used as a remedial measure, where filter operation is now impaired by organic growths.

Chlorination at this point is sometimes considered to be post-chlorination, because it is added after previous chemical treatment (4), (5), (7), (27), (29), (31), (32).

10. Maintaining Carrying Capacity of Mains

Biological growths within a pipe reduce the internal diameter and can be responsible for much corrosion. Slime-producing bacteria and filamentous growths of "iron" bacteria are frequently the predominating organisms in these growths.

Tuberculation may be caused by the presence of sulfate-reducing organisms. Hydrogen sulfide liberated during their life cycle reacts with chlorine and sometimes makes the maintenance of a proper residual chlorine level difficult. It is important when applying chlorine for control of these organisms that residuals are measured at the ends of the distribution or transmission mains.

The maintenance of free residual chlorine at all times in the system will prevent fouling by these organisms. The amount of chlorine required to do so will depend upon the total chlorine demand of the water (9), (12), (13), (17), (30), (38).

11. Controlling Organic Growths in Zeolite Beds

Free residual chlorination will prevent clogging of zeolite softening units by slimes and algal growths. The tolerance of the

synthetic zeolites for chlorine varies, and the manufacturer should be consulted before chlorination is started. Green-sand beds are not affected by normal residual chlorine levels.

If free residual chlorine is considered deleterious to the synthetic materials, de-chlorination is recommended. Occasionally, trichloromelamine for sterilization of the exchange bed is utilized to minimize loss of capacity and organic after-growths (29).

VI. Control of Break-Point Chlorination

Control of the Break-Point Process is obtained by means of special tests taken at certain specified points in the plant. In some cases this may be within five minutes of the addition of chlorine, while in others it may, of necessity, be 60 or more minutes later. The exact point of sampling for control purposes will depend upon the physical layout of the individual plant and the rate at which the ammonia content of the water is destroyed.

The object of Break-Point Chlorination is to produce and maintain a residual consisting essentially of free available chlorine, usually 85% or more. Since free available residual chlorine alone can exist only beyond the break-point, the process is controlled by making certain a definite free available residual has been produced that is adequate to carry through the plant and into the distribution system.

Best control is obtained by the establishment of at least two sampling or control stations. Their location within the plant will depend upon local conditions. The *first* should be close enough to the point of chlorine application to permit quick changes in chlorine feed rates, yet far enough away to allow for a degree of reaction between the chlorine and ammonia. A point from 10 to 30 min. after chlorination will usually suffice. The *second* should be located at either the top of the filters or at the high-lift pump, or both.

The difference between the free available residual chlorine at the various control stations will be the chlorine requirements of the water for the intervals between the various control points. The residual at the first control station will, therefore, usually be greater than at any subsequent control point. (An average free available residual of 1.0 ppm on top of the filters is main-

tained in a large number of places.) Fluctuation in the chlorine requirement between these control points with such a residual can be easily met. Fluctuations in chlorine requirements to maintain low residuals (0.10 to 0.20 ppm) may leave the water devoid of chlorine over a period of time. It is on such occasions that bacteria have a chance to pass through the plant, a circumstance always to be avoided.

To obtain a residual of 0.8 to 1.2 ppm on top of the filters may require free available residual chlorine of 3.5 to 4.0 ppm at the first sampling station in the summer and as low as 1.5 ppm in the winter. Sunlight, particularly, reduces residual chlorine in water. This de-chlorinating effect does not take place where basins are covered. Where the basins are open, it is sometimes necessary to establish chlorine feed rates for a clear day, cloudy day, and night operation. Experience will dictate the proper relation between the residuals at the various control stations (1), (2), (3), (15), (22), (23), (26), (28), (37).

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WEATHER CYCLES AND RAINFALL

BY ROBERT L. HENDRICK*

[*Read December 18, 1958.*]

I. The Search for Predictable Cycles

If there is anything common to all of nature, it is change. We find nothing static in nature, and many of nature's changes demonstrate a tendency toward cyclic behavior. This is true of our atmosphere.

We are all aware of the rhythmic nature of weather changes: alternating wet and dry days; a week of rain is followed by the rainless week, only to be followed in turn by the rainy week again. Down in Connecticut 1955 was our wettest year; this was followed by a normal 1956; then came our driest year, 1957. And now it has turned wet again. And so it goes on all time scales—an ice age is followed by an interglacial period; then the ice comes again.

The search for repeating cycles has been in progress since man first noticed that one week, one season, or even one decade varied from another. The more or less rhythmic changes in weather patterns were noted well before we began to accumulate climatological data to prove or disprove their existence. Every weatherwise farmer detected, or thought he detected, these cycles during his lifetime and made his own extrapolations into the future, based on his past experience.

It was inevitable that a faith was established that the accumulation of a long climatological record would eventually reveal the nature of weather cycles and lead to long-term predictability of weather trends.

Now, midway in the twentieth century, with 50 to 200 years of rainfall and temperature records in our libraries, we might be able to appraise our progress and our chances for success in uncovering cycles which show sufficient regularity of recurrence to render the future predictable.

If cycles of a predictable nature in rainfall or any other

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weather element actually exist, these cycles will be determined only if their periods are short enough to appear several times in the climatological record, or if the dynamical causes of the cyclic behavior are discovered and are in turn predictable.

II. The Present Stage of Long-Range Forecasting

The present status of long-range forecasting, and by long range I mean anything beyond one week in the future, gives proof that our hopes of finding some predictable rhythm in weather-pattern changes have not been realized. We are still not certain whether or not the weather-pattern variations, or the causes of weather variations, occur in a random fashion over time. If they prove to be random, they will also prove to be unpredictable.

Modern meteorology has made some exciting advances in understanding some of the dynamics and physics of atmospheric behavior. And dynamical principles have led to good forecasts of circulation patterns up to 3 days in advance. But due to the many complicated feed-back processes operating in the earth-atmosphere system, the dynamics themselves are not predictable, and therefore dynamical forecasts break down over a rather short period of time.

The search continues, with recent developments in statistics now being applied to the climatological record, in an attempt to make past weather reveal future weather. The modern search for useful cycles in weather patterns has available to it high-speed computing facilities for processing the ever accumulating store of historical data and for applying such mathematical techniques as time-series analysis, harmonic analysis, spectral analysis, discriminate analysis, both linear and non-linear regression analysis, and many others. These techniques are being used in analyzing the historical data, in an attempt to bring to light something that repeats, trends, or varies in some predictable manner.

Some important success in short-range forecasting can be attributed to some of these statistical techniques. At the Travelers Research Center in Hartford we are using linear regression techniques and find that the historical data do contain some statistical relationships that are useful in prediction for normal

short-range periods up to 2 days in advance. Similar techniques are now being applied to the longer-range time scale. We are trying to derive useful statistical relationships that will hold up on forecasts over periods ranging from 1 to 3 months. In another year or so we shall probably know whether or not this approach has a chance of being useful in a practical sense.

The science of meteorology, it must be confessed, has not as yet reached the age of long-range forecasting. We talk glibly of controlling the weather, but we really know that we can't control it unless we can forecast it, and we can't forecast it unless we understand it, and we can't understand it unless we are able to observe it in great detail.

We are still in the observing stage, where copious observations have led to some limited understanding, where limited understanding has led to a fair skill in short-range forecasting but almost no skill in long-range forecasting, and where weather control remains a myth, the claims of rainmakers notwithstanding.

In fact, we have just arrived at the time in our developing science where we may reasonably make forecasts of future forecasts. We now know that the simple predictable weather cycle will never appear. Cycles are obscured by other cycles. We are just beginning to grasp the enormous complexity of the sun-earth-atmosphere system, and we are able to see for the first time the full magnitude of the task of predicting atmospheric processes and resulting weather for extended periods into the future. We expect to progress, but our progress will most assuredly be slow. The great breakthrough into accurate long-range prediction is not in sight; it would be naive to plan on such a breakthrough, but it would be unduly pessimistic not to anticipate some real progress.

III. Variability of Rainfall

Perhaps more than any other weather parameter, rainfall appears to be random in its variations over time. Some rainfall cycles have been ferreted out of the records and related to dynamic causes, such as the higher frequency of thundershowers during afternoon hours, summer-season rainfall and winter dryness in New Mexico, and the reverse in California. But, for the

most part, above- and below-normal rains from one week to the next, from one season to the next, or from one decade or century to the next—these changes have not been related to any dynamic cause and do not show predictable cyclic behavior.

Although the climatological record has not yet revealed the atmosphere's predictable cycles to us, it does have some information for us concerning the variability of which the atmosphere is capable. The limits which the atmosphere sets upon its own variability become an important consideration in planning for the future. The application in planning for future water supplies is perhaps the most obvious. In preparing for the future water needs of an expanding population with its expanding industry and agriculture we turn to the climatological record and ask of it, "How dry can it get? How wet can it get?" We design according to the interpretation we give to the rainfall records that are available.

As the sun pours its energy into our atmosphere, stresses and strains develop which cause the atmosphere to make the varieties of weather we observe. The limits of atmospheric behavior and weather are determined by the atmosphere's ability to handle the energy that the sun has made available to it. If we are to know the real limits of our weather, we must first know something of the variability of the available solar energy and have a better understanding of how the atmosphere receives, transforms, transfers, and finally gets rid of this energy. Lacking this understanding, we must turn to our climatological record and learn what we can from it regarding possible weather extremes in the future.

In looking over the Hartford rainfall record the other day I was struck by the randomness of the monthly and annual figures and by the limits of variability shown to date. Monthly rainfall has shown a variation during this century from 0.18 in. to 21.87 in. —122 times as much rain in one month as in another. We find annual rainfall ranging from 32 in. in 1957 up to a high of 63 in. just 2 years before, in 1955. In over 50 years of record the high and low years are just 2 years apart. No trend is indicated there, only increasing variability, and we can expect this apparent variability to continue to increase as the climatological record grows longer. This is not because the atmosphere is actually

becoming more variable, but rather that the atmosphere has not had sufficient time to show us what she is capable of in our short period of record. This was rudely demonstrated to us in and around Hartford on August 19, 1955, when more rain fell in a single day than had ever been previously recorded during an entire month.

Again referring to Hartford rainfall during 1955, this year presents us with something of a paradox, for even though its total rainfall of 63 in. is the highest annual total of record, this same year holds 3 monthly records for dryness. January, May, and December of that year were the driest on record. So here we have a wet year and dry months getting all mixed up together, pretty well obscuring any trend that may actually exist in atmospheric behavior. And since 1955 we have seen a wide variety of changes, with 1956 about normal, 1957 the driest year on record, and during 1958 the rains have come back again in abundance. And so it goes, the trends and the limits of variation showing up as we look behind us, while future trends, cycles, and extremes remain quite obscure.

Just before coming down to Boston I took a quick look at the Boston rainfall record, extending back 140 years. This relatively long record shows monthly rainfall varying from only a trace up to 17 in. In general, annual variations appear quite random with the exception of a very distinct rainy cycle some 100 years ago. This rainy cycle of the last century is so pronounced that I can't help but question the validity of the Boston data for this period. I have not checked on the reliability of the old Boston records, nor have I compared them with nearby towns, but nevertheless here is what the record shows.

For 38 years, 1818 through 1855, the average yearly rainfall was 42 in. with only 2 years during that 38-year period having a rainfall of more than 50 in. Then, during the next 9 years, 1856 through 1864, all years had more than 50 in., the average being over 55 in. It is a sudden and remarkable change, indeed a rather frightening change, when a 9-year average exceeds the highest single annual total over the previous 38 years. Bostonians of 100 years ago must have wondered how long the rainy cycle would last and how extreme it might become. The extreme year was 67 in.; the rainy cycle lasted 23 years, from

1856 through 1878. During this period 18 of the 23 years had annual rainfall in excess of 50 in., the average being just over 53 in. Then, as abruptly as it began, the rainy cycle ended, and since 1878 we find the average annual rainfall 39.5 in. with only 2 years of the past 80 exceeding 50 in. A slight trend toward increasing dryness has been evident during the twentieth century, with the 12-year period, 1939 through 1950, showing an average of only 36.6 in. Since 1950 rainfall has been heavier and quite erratic from year to year.

What's next for Boston? Another rainy cycle just around the corner, a further increase in dryness during the last half of this century, or perhaps only relatively stable normal rainfall? We have no idea; the past record refuses to tell us, and we don't understand the dynamics.

More or less random cycles in weather and climate appear in all time scales, including the scale of thousands and even millions of years. It is in the long-term evidence that we gain some measure of appreciation of the true variability of the atmosphere and the inadequacy of our relatively brief climatological record as a guide to the limits of weather variability. We learn from strong, though indirect, evidence that hundreds and even thousands of feet of ice have covered New England on at least four different occasions in geological history. But these ice ages have not shown sufficient regularity, nor have dynamic causes been determined, to the point where we can say anything concerning if and when the ice will come again. My guess is that it will come again, but my argument is only that it appears that ice is just a part of the fluctuating balance of energy exchange between earth and sun.

IV. Planning for the Future

But you gentlemen are no doubt more interested in the more practical problems of today. It is your job to intercept, for our beneficial use, a part of that rainfall that falls upon New England. Will you be able to intercept enough in the years and decades ahead—will you be able to get rid of any excess? My only advice to you is to plan with a broad margin. The fallibility of a 50-100- or even 150-year climatological record as a guide was shown in Connecticut in 1955, when the highest previous

monthly rainfall total was exceeded in a single day. One hundred years are nothing in the time-scale of earth-solar processes. Could these processes be operating so as to bring us, in the coming decades, a month with 40 in. of rain, or perhaps 2 or 3 consecutive months without a drop of rain? Probability says that the chances are exceedingly small. But probability itself is dependent upon what has been recorded in the record books.

We must, of course, use our climatological record as the best available guide, but at the same time we should remain fully aware of the fact that the atmosphere has not yet had time to show us what she is capable of. Our future planning on water supplies should, within the limits of economic feasibility, take into account the possibility of rainfall deficiencies and excesses beyond those that show in the record books. That this has been your policy in the past was demonstrated, at least in Connecticut, by the ability of the principal Connecticut reservoirs to withstand the unprecedented rainfall and floods of 1955 without major loss.

I should like very much to be able to tell you something about the rainfall cycles, trends, or extremes that will prevail here in New England in the months, years, and even decades that lie ahead. But research along these lines has not been fruitful in a practical sense. Perhaps this situation will change as we slowly, ever so slowly, gain in our understanding of how the sun drives the atmosphere and makes the atmosphere say rain for one month or year and little rain for the next month or year.

One interesting prediction has been made for New England. Hurricane winds and rains have been forecast to be less frequent in the decades ahead than they have been in the past decade. This prediction is probably a good one, for highly abnormal weather must either return to normal or the normal itself must change. While we do not know what the real normal may be or what may come to be considered to be normal in the future, it does appear that the high frequency of tropical storms in and near New England during the past decade or two has been the result of an anomalous fluctuation in the general circulation of winds over the northern half of the world, and this wind pattern has already returned to what we consider a more normal state.

Dr. Willett of M.I.T. has related these circulation changes

to cyclic sunspot behavior. Based on the more or less regular components of sunspot cycles, he has stated an interesting case for a return to generally colder temperatures, snowier winters, and less tropical storminess in New England during the remainder of this century. In my opinion Dr. Willet's long-range outlook is as soundly based as any that are being made; nevertheless, the physical relationships between solar disturbances and atmospheric behavior are almost totally unknown.

Past data, despite its deficiencies, remains our most powerful tool for probing the future. It occurs to me that in planning for future water supplies and the controlling of future floods a joint effort of water experts, engineers, and meteorologists-climatologists should produce the most fruitful results. To the knowledge of water requirements and engineering know-how now available to water-works engineers, the meteorologist-climatologist should be able to contribute useful interpretations of past weather data as they relate to future extremes and variability. And we hope that eventually the meteorologist will be able to apply real skill in long-range prediction to the water-supply problems.

While we continue to search for the predictable cycles and trends in weather and the predictable dynamics of the earth-sun energy system, let us plan on much normal weather—that is, weather as we have observed and recorded it in the past—but with occasional surprises that will alter the record books.

SIMPLIFIED ANALYSIS OF COMPLEX WATERWORKS DISTRIBUTION NETWORKS

BY EDWIN B. COBB*

[*Read January 15, 1959.*]

Perhaps the writer is old-fashioned, but even in this age of high-speed electronic computers, he believes that there is still a place for a simple method of analysis for waterworks networks—one which can be applied at the engineer's desk.

On March 17, 1955, the writer presented a paper before this Association titled "The Analysis of Complex Waterworks Distribution Networks."† This analysis used a trial-and-error approach and required special accessories, consisting of wooden disks and paper scales. Since it was a trial-and-error procedure, some patience and intuition were required to reach useful solutions. The special accessories necessitated a period for manufacture and had an inconvenient habit of not being available in sufficient numbers when needed. The paper scales were tedious to make and required some skill in drafting. Difficulty was sometimes encountered in selecting the proper scale interval when a network included both short lengths of large pipe and long lengths of small pipe.

While the above method provided a means for analyzing complex networks where a method of analysis for such networks had previously been generally lacking, its shortcomings led the writer to search for improvements. This search has been rewarded by the development of a system which eliminates the trial-and-error feature and all accessories, except for some simple paper scales.

In the interest of making this useful tool available to the average waterworks engineer, the method of analysis will be presented in a simple manner, using a typical problem to illustrate the technique. Also for the sake of clarity, the writer will repeat certain basic concepts discussed in his earlier paper.

There are two types of waterworks networks, and to differ-

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entiate between them, the writer has coined the terms "Simple Network" and "Complex Network." A simple network is one which is supplied at a single point. A complex network is one which is supplied at two or more points by sources which have rates of input dependent upon the resistance to flow in the system.

A simple network is illustrated in Fig. 1. The source of supply of the network is indicated as a standpipe, but a pump or other source could have been substituted.

One type of complex network is illustrated in Fig. 2. The pipe arrangement is similar to that shown for the simple network in Fig. 1, but in this case the supply is from two standpipes, *A* and *B*, which are at different elevations. Centrifugal pumps could have been substituted for one or both of the standpipes. For simplicity, no outflow has been considered from any of the intermediate junctions.

In the complex network shown, the sum of the inflows from the two standpipes must equal the outflow from the system at *C*. Also, the algebraic sum of the losses in each pipe by any route from *A* to *C* must equal the available head between *A* and *C*. Similarly, the algebraic sum of the losses by any route from *B* to *C* must equal the available head between *B* and *C*. Furthermore, the algebraic sum of the losses by any route between the standpipes must equal the difference in water levels between the two tanks.

Any network can be analyzed by a trial-and-error procedure for the flow pattern under a given set of conditions, by means of only a slide rule or pipe flow table, provided one has sufficient time and patience. Hardy Cross proposed mathematical solutions applicable for both simple and complex networks, although he did not differentiate between them. The Hardy Cross method of "balancing flows" works very well with simple networks, but his method of "balancing heads," while theoretically suitable for complex networks, has been found by the writer's experience to be tedious and probably impracticable for general use.

The analog-type computer, such as the McIlroy Network Analyzer, should be able to analyze complex networks readily. Such equipment has limited availability, however, and is too expensive for the average waterworks engineer's office. The use

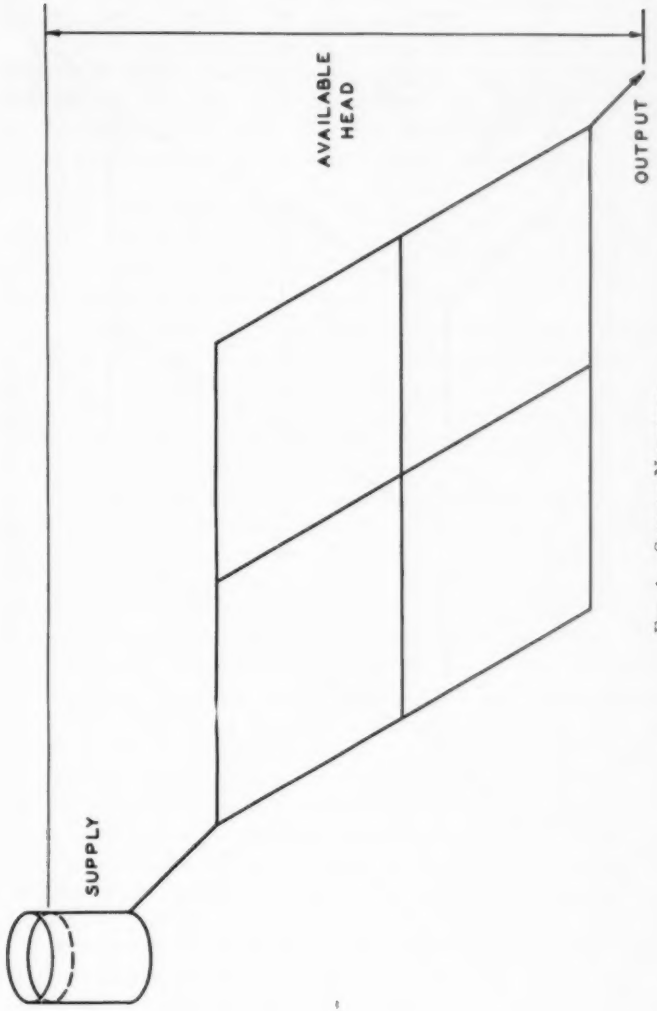


FIG. 1.—SIMPLE NETWORK.

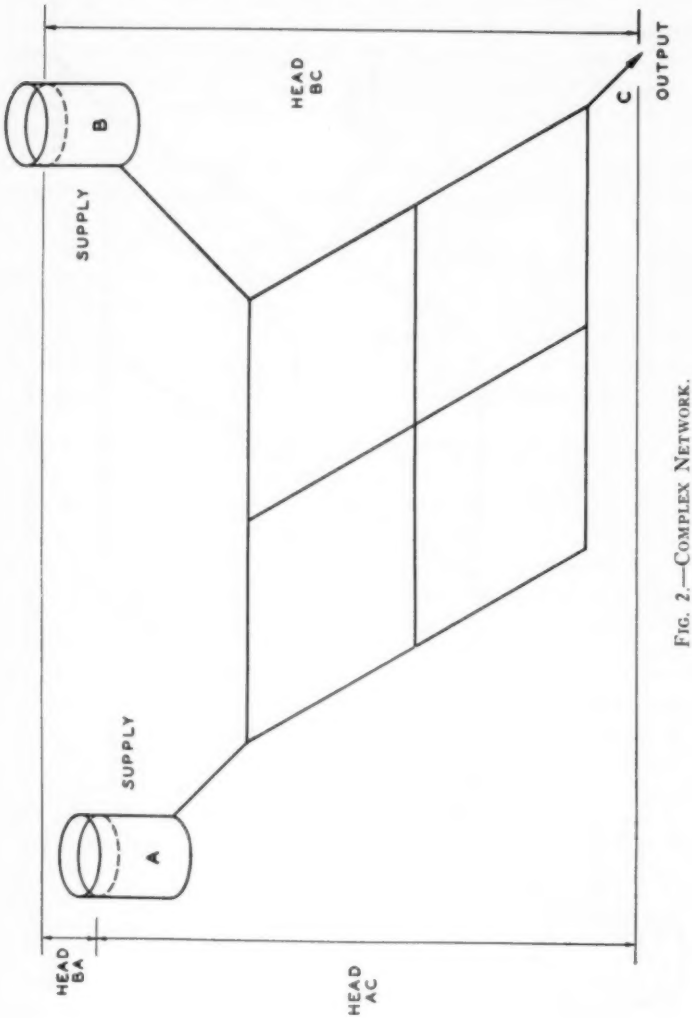


FIG. 2.—COMPLEX NETWORK.

of rented equipment, where available, may involve time and expense not justified by the solution sought.

The digital-type computer could also be used to analyze complex networks, but unless the engineer has such equipment available in his office and understands the required programming technique, the time and expense involved in the use of rented equipment or service may not be justified by the solution sought.

The method described in the writer's previous paper provided a method for analyzing complex networks at small expense in the engineer's office. That method unfortunately has the shortcomings described previously.

The simplified procedure described in this paper is designed primarily for complex networks. It could be used equally well, however, with simple networks, but it is doubtful if in many cases with such networks it could compete successfully with the conventional Hardy Cross method in the time and effort required to reach a useful solution.

The basic principle of the simplified analysis can be readily shown by consideration of a typical junction in a waterworks network. In Fig. 3a is shown a junction of three pipes, 12-, 10-, and 8-in. size respectively. Flow is assumed from point *A* to junction *O*, where it divides into two parts and flows to points *B* and *C*. The hydraulic grade at points *A*, *B*, and *C* have been indicated as El. 100, 90, and 80, respectively, and are assumed to be determined by other considerations in the network. Because the flow is from *A* to *B* and *C*, the elevation of the hydraulic grade at *A* must be higher than its elevation at both *B* and *C*. The relative elevations of the hydraulic grade at points *B* and *C*, together with the relative frictional resistances of the 10- and 8-in. pipe, determine the relative discharges at *B* and *C*.

The elevation of the hydraulic grade at *O* is unknown and must be determined, if the relative discharges at *B* and *C* are to be computed. Since in any junction the inflow must equal the outflow, the flow through the 12-in. pipe must equal the sum of the flows in the 10- and 8-in. pipes. It becomes evident, therefore, that the hydraulic grade at *O* must be at such an elevation as to provide sufficient drop in hydraulic grade from *A* to induce a flow in the 12-in. pipe which would equal the sum of the flows

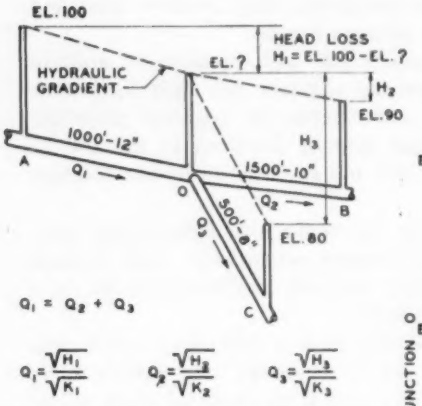


FIG. 3A TYPICAL JUNCTION

PIPELINE K FACTORS

LINE	SIZE	LENGTH	C**	J*	K*	$\sqrt{K}$
AO	12"	1000'	120	.00127	1.27	1.13
OB	10"	1500'	120	.00317	4.75	2.18
OC	8"	500'	120	.00964	4.82	2.20

* SEE APPENDIX B
** H.&W. COEF. C

H-FT.	$\sqrt{H}$	Q MGD AO	OB	OC
0	0	0	0	0
1	1	0.89	0.46	0.46
2	1.41	1.25	0.65	0.64
3	1.73	1.53	0.79	0.79
4	2.0	1.77	0.92	0.91
5	2.24	1.99	1.03	1.02
6	2.45	2.17	1.12	1.11
7	2.65	2.35	1.22	1.20
8	2.83	2.51	1.30	1.28
9	3.0	2.66	1.38	1.36
10	3.16	2.80	1.45	1.44

FIG. 3C COMPUTATION OF FLOWS FOR SCALES

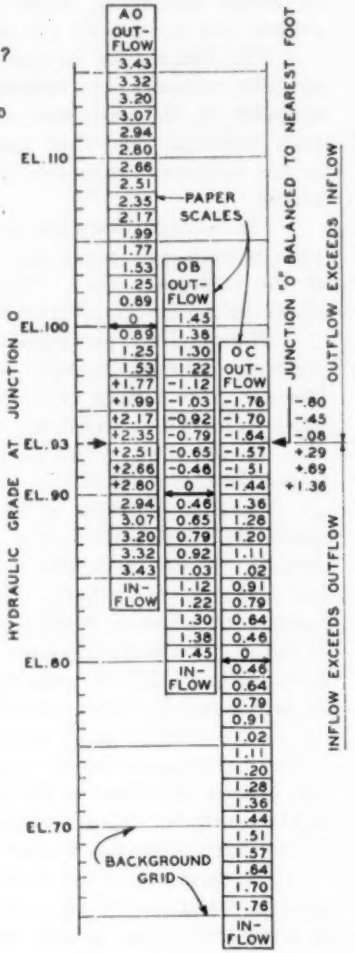


FIG. 3B SCALE ARRANGEMENT FOR BALANCED FLOW AT JUNCTION

FIG. 3.

which would simultaneously be induced by the drops in hydraulic grade in the 10- and 8-in. pipes.

As a rapid means of determining the elevation of the hydraulic grade at O, the writer has devised a simple arrangement with paper scales as shown in Fig. 3b. Each scale represents one of the three pipelines. The scales are laid on a grid background of convenient scale interval, in which each interval represents a 1-ft difference in elevation of the hydraulic grade at junction O. Each scale is also marked off in intervals equal to that of the background grid. A line in the center of each scale is marked as zero. At the first interval on each side of the zero line, the rate of flow for a 1-ft drop in hydraulic grade (loss of head) for the applicable pipeline is written in. Flows are in mgd (million gallons per day). At the next interval in either direction the flow for a 2-ft loss in head is written in, and so forth until the entire scale is filled. The required length of scale can be readily estimated by the drop in hydraulic grade possible in the respective pipelines under the given conditions.

A convenient method for computing the flows at various losses of head at 1-ft intervals for use in making the scales is indicated in Fig. 3c. This method employs an adaptation of the Darcy formula, but other formulas, such as the Hazen and Williams, can be used to suit the engineer's personal preference.

The adaptation of the Darcy formula is in the form:

$$Q = \frac{\sqrt{H}}{\sqrt{K}}$$

in which $K = \dfrac{fl}{2gDA^2}$

This form was discussed in the writer's previous paper, but for convenience the discussion is repeated in revised form in Appendix B.

The scale for the 12-in. line is placed on the grid so that its zero index coincides with the elevation of the hydraulic grade at A. The scales for the 10- and 8-in. lines are similarly positioned on the grid for the respective elevations of hydraulic grade at B and C.

The flows below the zero index on the scales are considered inflows to the junction and are designated (+). The flows above

the zero index are considered outflows from the junction and are designated (—). By adding algebraically the flows indicated on the scales at each elevation across horizontally, it will be noted that at some elevation on the background grid these sums will approach zero. In the example this occurs at El. 93. Thus, to have the inflow equal to the outflow in this example, the hydraulic grade at junction *O* must be at El. 93. From the head loss in each pipe the respective flows may be quickly determined; in this case from the readings on the scales.

Since the scales are marked off at 1-ft intervals, an answer only to the nearest foot was obtained. By interpolation or by using a smaller scale interval, a closer answer carried to any accuracy desired may be obtained. For most practical hydraulic problems, however, an accuracy of the nearest foot is generally adequate, with occasional interpolations to 0.5 ft.

Any change in the elevation of the hydraulic grade at *A*, *B*, or *C* would alter the flows and would affect the elevation of the hydraulic grade at *O*. The revised elevation can be quickly determined, however, by adjusting the scales to the revised elevations and determining the required elevation in the same manner as before.

We will now consider the application of the use of the scale assembly to the solution of a network problem. The complex network of Fig. 2 is shown in Fig. 4 with the hydraulic grade lines sketched-in. If this were a problem to be solved, the elevations of the hydraulic grade at points *A*, *B*, and *C* would be known. Could we determine the elevations of the hydraulic grade at the intermediate junctions, then we could compute the rates of flow in the various lines, together with the inflows at points *A* and *B*, and the outflow at point *C*.

To solve the above problem by the simplified method, we first assume a value for the elevation of the hydraulic grade at all junctions in the network where it has not been previously established. Using these assumed values, we determine by means of the paper scales a corrected value of the elevation of the hydraulic grade at each junction in relation to the values assumed at the adjacent junctions. Generally the corrected value is different from the assumed value. After all junctions have been analyzed in turn, the corrected values of the elevations of the hydraulic grade are substituted for the assumed values.

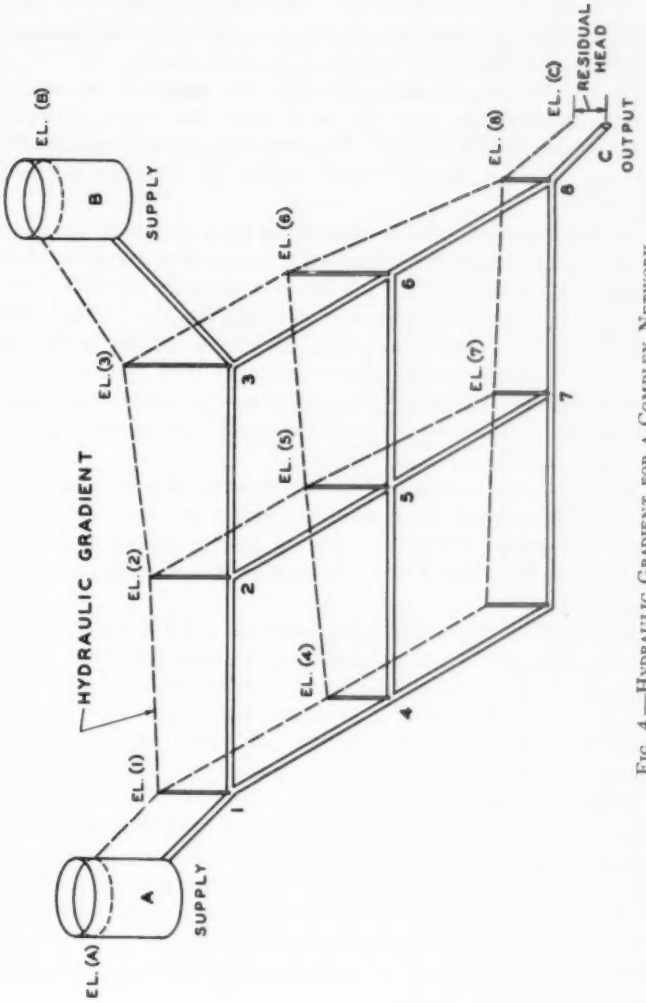


FIG. 4.—HYDRAULIC GRADIENT FOR A COMPLEX NETWORK.

Each junction is then re-analyzed, and a new set of elevations of the hydraulic grade is obtained. Successive repetitions of this procedure gradually bring the elevations of the hydraulic gradient at the junctions nearer and nearer to the true values.

By providing convenient methods for handling the scales and for recording the data for each trial, the entire network may be analyzed with facility. Convergence will be found to be rapid and may be carried to any degree of accuracy deemed necessary.

To illustrate procedure in detail, we have prepared a typical network problem and have carried through the solution to a reasonable balance. In Fig. 5a is shown a complex network, consisting of nine junctions and four circuits. Supply is from two standpipes and a centrifugal pump. A known discharge occurs at junction *G* in the center of the network. The problem is to determine the discharge at junction L at the lower right-hand corner of the network when the elevation of the hydraulic grade at that junction is maintained at El. 30.

The first step is to make the paper scales required for each junction. The method for making the scales has been described in sufficient detail, except in the case of the supply from the centrifugal pump. The method of making this scale is described in Appendix A.

At junction *L* the outflow has been assumed as at the junction, and since the hydraulic grade at this point has been given as fixed at El. 30, the discharge must at all times be equal to the inflows in pipes *HL* and *KL*. It is not necessary, therefore, to provide a set of scales for this junction, and scale assemblies are necessary then at only eight junctions.

Two scales each are required for 10 of the pipes which are included in two scale assemblies. The connections from the standpipes and the pump and pipes *HL* and *KL* are included in single scale assemblies; thus only single scales are required for these lines. In the latter group, flow in these pipes obviously can be in one direction only; thus half-scales are all that are required for these pipes. The scale for the pump connection is in a special category.

The layout of the scale assemblies for the eight junctions is shown in miniature in Fig. 5b with the arrangement for one of the trials in the solution. At junction *G* there is a constant

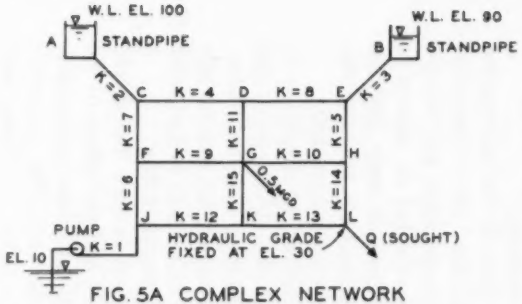


FIG. 5A COMPLEX NETWORK

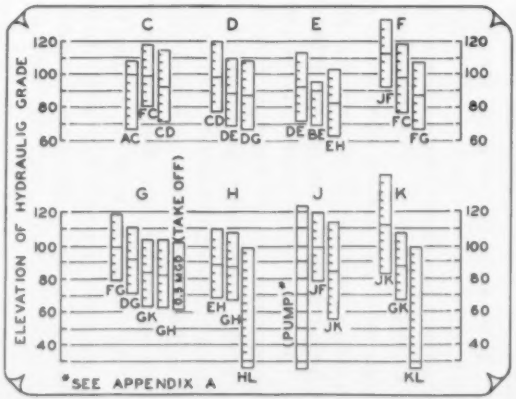


FIG. 5B ARRANGEMENT OF SCALES

JUNCTION AND TAKE OFF	ADJACENT JUNCTION	ASSUMED ELEVATIONS		CORRECTED ELEVATIONS 1ST TRIAL		2ND TRIAL		3RD TRIAL		FINAL ADJ
		JUNCTION	ADJACENT JUNCTION	JUNCTION	ADJACENT JUNCTION	JUNCTION	ADJACENT JUNCTION	JUNCTION	ADJACENT JUNCTION	JUNCTION
COL. 1	COL. 2	COL. 3	COL. 4	COL. 5	COL. 6	COL. 7	COL. 8	COL. 9	COL. 10	COL. 11
	A		100		100		100		100	
C	D	97	91	97	91	98	91	98	92	98.5
	F		97		98		98		99	
	C		97		97		98		98	
D	E	91	88	91	89	91	89	92	88.5	92
	G		88		86		87		87	
	D		91		91		91		92	
E	B	88	90	89	90	89	90	88.5	90	89
	H		81		82		81		82	
	C		97		97		98		98	
F	G	97	88	98	86	98	87	99	87	99
	J		110		111		112		112	
	D		91		91		91		92	
G	H	88	81	86	82	87	81	87	82	87.5
0.5	K		83		83		83		83.5	
	F		97		98		98		99	
	G		88		86		87		87	
H	E	81	88	82	89	81	89	82	88.5	81.5
	L		30		30		30		30	
	F		97		98		98		99	
J	K	110	83	111	83	112	83	112	83.5	112.5
	PUMP									
	J		110		111		112		112	
K	G	83	88	83	86	83	87	83.5	87	83.5
	L		30		30		30		30	

FIG. 5C TABULATION OF RESULTS

FIG. 5.

outflow of 0.5 mgd. To insure that this outflow will not be overlooked when balancing the flow at that junction, a blank scale with 0.5 on it has been added to its scale assembly.

The method of tabulating the results of each trial is shown in Fig. 5c. In Column 1 of the tabulation the junctions are listed in a convenient order, and the amounts of the known takeoffs are also indicated as a reminder. In Column 2 the junctions tributary to each respective junction in Column 1 are listed. In Column 3 the given or assumed elevations of the hydraulic grade as applicable for the respective junctions are listed, and in Column 4 these elevations are listed opposite the appropriate adjacent junctions. The elevations underlined in Column 4 indicate those which are given with the problem.

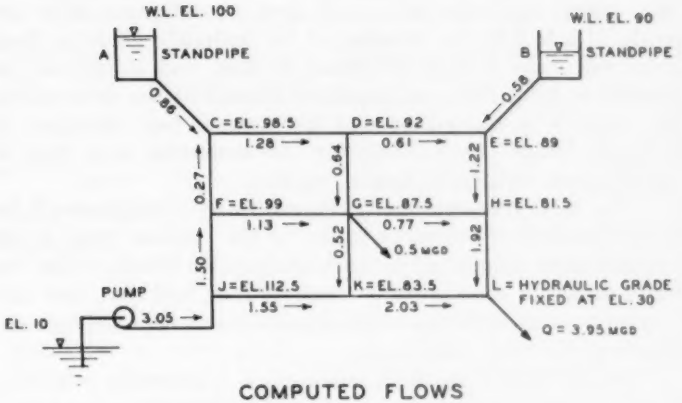
With the above information as a guide, the paper scales are arranged on the background grid with the zero indexes of each scale at the appropriate elevations. A corrected value of the elevation of the hydraulic grade at each junction is next determined in the manner described previously, and these values are entered in Column 5. These same values are also entered in Column 6 for the appropriate adjacent junctions.

The next step is to adjust the paper scales to the appropriate corrected elevations and to determine another set of corrected elevations for all junctions. These corrected values are entered in Columns 7 and 8. The procedure is repeated in successive steps, until the relative changes in elevation at each junction become so small as to indicate that the correct elevations of the hydraulic grade throughout the network have been reached.

The number of trials may be extended at the discretion of the engineer. In the example certain of the elevations of the hydraulic grade were carried to 0.5 ft to give a better mathematical check on the result. This was necessary because certain of the lines were of such size that small differences in hydraulic grade made substantial differences in the computed flow.

As a final check on the results, the flow in each line should be computed from the hydraulic gradients, and the inflow to the network checked against the outflow. As an added precaution, the balance at each junction may be checked. The computed flows in the network example and final checks have been indicated in Fig. 6.

In general, the biggest difficulty in obtaining a mathematical



COMPUTED FLOWS

FINAL CHECK ON RESULTS

TOTAL INFLOW - MGD		TOTAL OUTFLOW - MGD	
AC	0.86	TAKE-OFF	0.50
BE	0.58	KL	2.03
PUMP	3.05	HL	1.92
	4.49		4.45

JUNCTION	INFLOW-MGD	OUTFLOW-MGD
C	0.86 + 0.27 = 1.13	1.28
D	1.28	1.25 = 0.64 + 0.61
E	0.58 + 0.61 = 1.19	1.22
F	1.50	1.40 = 0.27 + 1.13
G	1.13 + 0.64 = 1.77	1.79 = 0.77 + 0.52 + 0.50
H	1.22 + 0.77 = 1.99	1.92
J	3.05	3.05 = 1.50 + 1.55
K	1.55 + 0.52 = 2.07	2.03

FIG. 6.—BALANCED NETWORK AND CHECKS.

balance will arise when a network contains some large pipe of short length and relatively small flow. A difference of a few tenths of a foot in the elevation of the hydraulic grade in these cases will make a large difference in flow, and it will not be possible to get a close mathematical balance of the flows unless the analysis is carried beyond the nearest foot elevation of hydraulic grade. Only judgment can determine how close a mathematical balance of flow is justified.

The most time-consuming element in most analyses will be the preparation of the paper scales. If the engineer plans to do a considerable amount of network analysis, he should retain the scales made for each problem, since he may find that they can be used in other problems where pipeline resistances are approximately of the same magnitude.

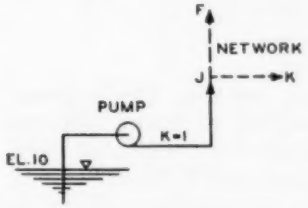
Once a system has been balanced, it is generally relatively easy to determine the effect of different-size pipelines in selected locations. Similarly, the effect of pumps of different capacity or of different reservoir water levels can be readily assessed.

In network analysis it is prudent to simplify the network to the fullest extent practicable. Since the consumption from the average waterworks system varies from second to second and from area to area, it is necessary to assume conditions as of some instant as the basis of analysis. The estimation of the amount and distribution of consumption for such instant may be subject to appreciable errors. In addition, the friction characteristics estimated for the various pipelines are based most commonly on experience and judgment derived, at best, from a few sample tests. To test each pipeline in a network to determine its condition would generally be a difficult and expensive assignment, particularly for the larger-size lines. To obtain this information by measuring the discharge from hydrants would in most systems stir up so many complaints from dirty water that the engineer and waterworks staff would be exceedingly unpopular. Waterworks network analysis, therefore, even with the best formulas and most intricate electronic computers available, should not be considered an exact science, but rather, when applied with understanding, a most useful tool.

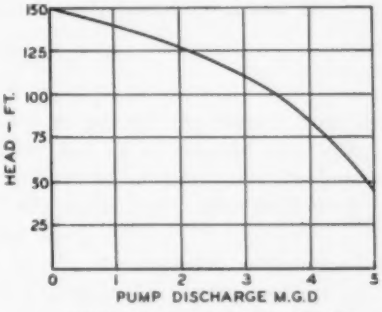
In closing, the writer wishes to acknowledge the assistance of Stephen L. Bishop of the staff of Metcalf & Eddy in preparing the various figures and examples used in this paper.

Appendix A

Method of Making Scale for Centrifugal Pump Supply.



CENTRIFUGAL PUMP WITH CONNECTION TO JUNCTION J

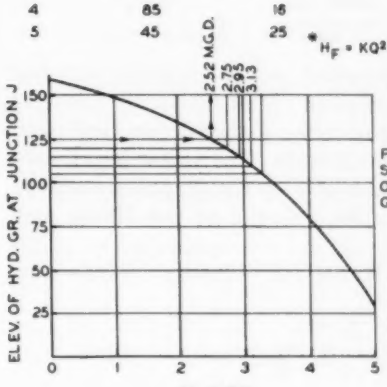


PUMP CHARACTERISTIC CURVE

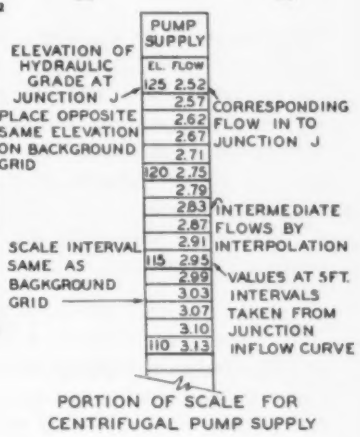
TRANSFER OF PUMP CHARACTERISTIC CURVE TO JUNCTION J

PUMP DISCHARGE M.G.D.	PUMP DISCHARGE HEAD-FT.	H_F-PUMP TO JUNCTION J * FT.	PUMP CHARACTERISTIC CURVE TRANSFERRED TO JUNCTION J-FT.	ELEVATION OF HYD. GRADE AT JUNCTION J
0	150	0	150	160
1	140	1	139	149
2	128	4	124	134
3	112	9	103	113
4	85	16	69	79
5	45	25	20	30

* $H_F = KQ^2$



INFLOW TO JUNCTION J



PORTION OF SCALE FOR CENTRIFUGAL PUMP SUPPLY

APPENDIX B

PIPE-FLOW FORMULA ADAPTED TO NETWORK ANALYSIS

It has been found that the Darcy formula for pipe flow,

$$H = f \frac{L}{D} \frac{V^2}{2g},$$

is most convenient for use in network analysis. This is principally true because in its use, only squares or square roots are involved, and these can be readily handled on the common polyphase slide-rule. Also, while the Hazen and Williams formula, $V = 1.318C\ R^{0.63}\ S^{0.54}$, gives fairly representative results for the smoother pipes ($C = 120$ or better), it is less suitable for the rougher pipes. The Darcy formula is more suitable for use with the rougher pipe.

The use of the Darcy formula is simplified when it is reduced to the expression $H = K\ Q^2$, in which

$$\mathrm{K} = \frac{fL}{2gDA^2}.$$

When Q is in mgd,

$$K = \frac{.0606\ fL}{D^5}.$$

Many waterworks engineers, however, are not familiar with the usual values for the friction coefficient (f) of the Darcy formula, but are accustomed to thinking in terms of the friction coefficient (C) of the Hazen and Williams formula. The writer has, therefore, prepared a table of the value of K in the simplified formula $H = KQ^2$ for common pipe sizes, referred to the Hazen and Williams coefficient (C).

To derive this table, the Hazen and Williams formula was rewritten in the form

$$H = \frac{LV^{1.85}}{1.667\ C^{1.85}\ R^{1.16}}$$

and equated to the Darcy formula in the form

$$H = f \frac{L}{D} \frac{V^2}{2g}.$$

The Darcy (f) was then solved for in terms of the Hazen and Williams (C) as follows:

$$f \frac{L}{D} \frac{V^2}{64.4} = \frac{LV^{1.85}}{1.667\ C^{1.85}\ R^{1.16}}$$

$$f = \frac{193.2}{C^{1.85}\ D^{0.16}\ V^{0.15}}$$

Values of f were computed for 8-, 12-, 18-, 24-, 36-, and 60-in. diameter pipe at velocities of 3, 4, and 5 fps for a series of values of C ranging from $C = 40$ to $C = 140$. Certain of the computed values of f have been plotted in Fig. B-1, to illustrate the relationship between f and C. Average values for f at various intervals of the value of C were taken from the curves, and these values were used to prepare Table B-1. In this table are tabulated values of K for the Darcy formula per 1,000 ft of pipe in sizes from 4-in. to 60-in., inclusive, for values of C from 40 to 140, inclusive.

In the simplified form, the Darcy formula lends itself to easy calculation for quantity of flow or loss of head in single pipe and the solution of pipe in series or in parallel:

1. *Single pipe*
   a. Loss of head $H = KQ^2$
   b. Quantity of flow $Q = \sqrt{\frac{H}{K}}$
2. *Equivalent friction coefficients* (K)
   a. Pipe in series $K_T = K_1 + K_2 + K_3 + \ldots K_n$
   b. Parallel pipe $K_e = \frac{1}{\left(\frac{1}{\sqrt{K_A}} + \frac{1}{\sqrt{K_B}} \right)^2}$

Additional discussion of the use of the Darcy formula for network analysis may be found in a paper by the writer, published in the October, 1944, issue of the Journal of the Boston Society of Civil Engineers. That paper also includes the use of this formula in the Hardy Cross mathematical method for analyzing simple waterworks networks.

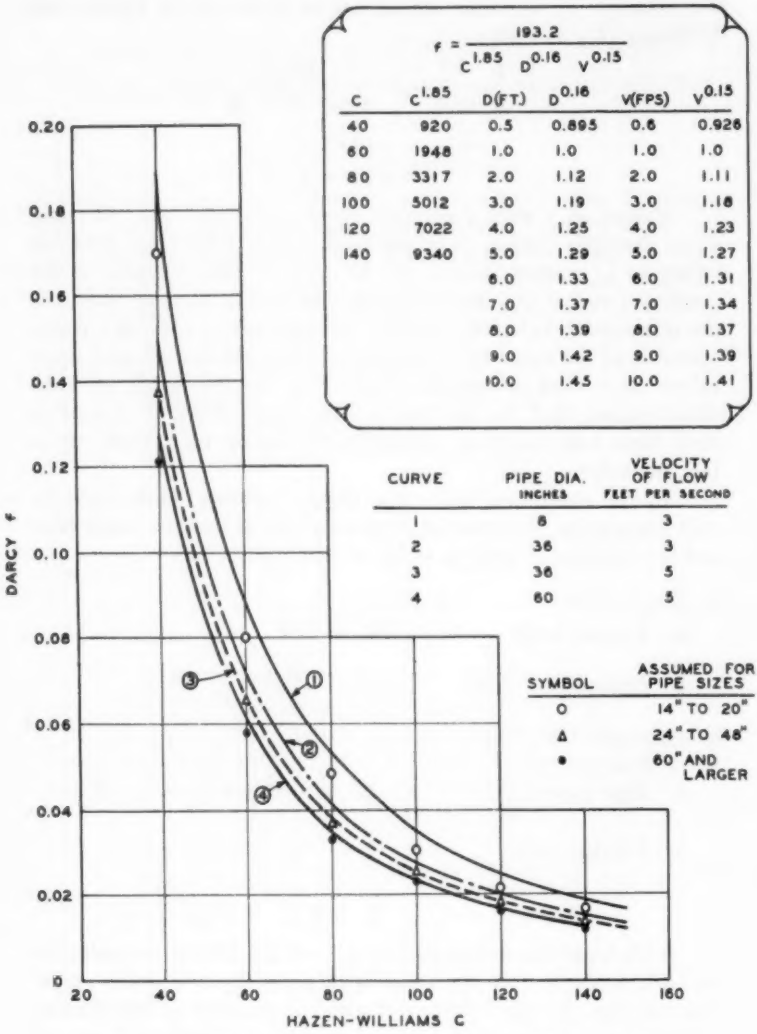


FIG. B-1.—RELATION OF DARCY f TO HAZEN-WILLIAMS C.

TABLE B-1.—VALUES OF DARCY K^* PER 1,000 FEET OF PIPE

Pipe size (in.)	H & W "C"	40	60	80	100	120	140
	Av. value Darcy "f"	0.170	0.080	0.048	0.030	0.021	0.016
4		2,516.	1,184.	710.	444.	311.	237.
6		330.	155.	93.1	58.2	40.7	31.0
8		78.0	36.7	22.0	13.8	9.64	7.34
10		25.7	12.1	7.25	4.53	3.17	2.42
12		10.3	4.85	2.91	1.82	1.27	0.970
14		4.78	2.25	1.35	0.843	0.590	0.450
16		2.45	1.15	0.691	0.432	0.302	0.230
18		1.36	0.638	0.383	0.239	0.168	0.128
20		0.799	0.376	0.226	0.141	0.098	0.075
	Av. value Darcy "f"	0.137	0.065	0.037	0.025	0.018	0.014
24		0.259	0.123	0.0699	0.0472	0.0340	0.0265
30		0.0849	0.0403	0.0229	0.0155	0.0112	0.00868
36		0.0341	0.0162	0.00921	0.00623	0.00448	0.00349
42		0.0158	0.00748	0.00426	0.00288	0.00207	0.00161
48		0.00811	0.00385	0.00219	0.00148	0.00107	0.000829
	Av. value Darcy "f"	0.122	0.058	0.033	0.023	0.016	0.012
60		0.00237	0.00113	0.000640	0.000446	0.000310	0.000233

* Q in mgd.

EXPERIMENTAL STUDIES OF CORROSION CONTROL BY SILICATES

BY ROLF ELIASSEN,* R. T. SKRINDE† AND W. B. DAVIS†

[*Read at Chemists' Session, March 19, 1959.*]

Corrosion research workers have used oxygen-depletion tests to measure corrosion rates since nearly the turn of the century. Wood (1), Brown *et al* (2), Forrest *et al* (3) and others have utilized such measurements in formulating fundamental principles of corrosion. In England much of the corrosion research work of Evans and Hoar (4), Wormwell (5), and Bengough *et al* (6) has been accomplished by means of oxygen-depletion studies.

A. Oxygen-Consumption Methods

There are various ways of employing the oxygen-consumption test. The so-called "oxygen drop" technique consisted generally of determining the dissolved oxygen of the water before and after exposure to the metal in long pipelines. The initial studies on silicate corrosion inhibition by Speller (7), Texter (8) and Russell (9) were conducted by the oxygen-drop method. Forrest *et al* rotated the specimens in liquid of known oxygen concentration and measured the oxygen concentration at the end of the test. Bengough *et al* (6) used a disc specimen fully immersed in water with oxygen in the space above the liquid. Use of oxygen from the space above the sample was taken as the rate of corrosion, but the apparatus for each individual sample was complex. Other forms of apparatus for oxygen-consumption corrosion tests have been described by Borgmann and Evans (10). Using stoichiometric relationships between oxygen utilization and the amount of iron required to combine with the oxygen, many of the early workers reported their results directly in weight of iron oxidized, in accordance with the following generalized reaction:

$$4Fe + 3O_2 + x\ H_2O \rightarrow 2Fe_2O_3xH_2O$$

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Although the use of oxygen consumption is a proven method of corrosion testing, many of the previous methods of measuring this parameter have been extremely cumbersome and unwieldy. The measurement of dissolved oxygen by chemical means is itself a time-consuming operation, and the same water cannot be re-used to continue the corrosion test. The use of long pipelines requires a large laboratory space for each circuit, and the inside surfaces of long pipes cannot be prepared easily as uniform corrosion specimens. Previous pressure-variation methods of measuring oxygen utilization have involved a large and complex assembly for each sample being tested. The use of pure oxygen in the air space above the samples caused higher corrosion rates than usual, and the quiescent conditions of the samples slowed down oxygen transfer to the corroding surfaces, thereby reducing corrosion rates in these cases. In view of the above limitations on the oxygen-depletion testing method, a more flexible and rapid technique for measuring the rate of oxygen absorption by non-destructive testing of the sample was sought. This resulted in the studies reported below, in which the Warburg respirometer was used.

B. Warburg Respirometer for Corrosion Research

Corrosion-testing methods based on manometric measuring of oxygen consumption have the advantage of giving complete corrosion-time curves from a single specimen. Since these curves are usually smooth, the effect of various environmental conditions on the corrosion rate with time can be investigated by noting the oxygen depletion as often as desirable. Manometric devices or respirometers of various types have been used extensively in the study of tissue metabolism since approximately 1900. The Warburg respirometer was developed by O. Warburg and his co-workers (11) at Berlin in the 1920's. It has since been used extensively in other fields, such as that of sanitary engineering, where the biological degradation of organic wastes is studied by this method. Its chief advantages are the extreme flexibility and speed by which many variables can be studied in short-term tests.

The Warburg method of measuring oxygen utilization is based on the change in pressure of a constant-volume system

resulting from the uptake of oxygen from that system. The reaction flask, containing the specimen and partly filled with corrosive solution, is attached to a manometer of which the fluid has nearly the same specific gravity as water. With the Warburg in operation (Figures 1 and 2), 18 such reaction-flask and manometer systems are immersed in a constant-temperature water bath. Constant motion of the specimens in the corrosive solution is maintained by an oscillating device. This action also agitates the surface of the water, which insures free diffusion of oxygen from the atmosphere above the sample to the liquid as it is being utilized. The large number of reaction flasks used simultaneously presents an opportunity for the study of many variables under controlled conditions.

As oxygen is absorbed in the corrosive water to form oxidized corrosion products, it is replenished to the solution from the atmosphere above in the reaction flask. The oxygen uptake causes a reduction of pressure above the fluid which is measurable on the manometer. Pressure variation in a system due to changes in temperature and atmospheric pressures are compensated for by a thermal barometer. Oxygen utilized at the time of a reading may be computed from the net pressure change by a method outlined by Umbreit *et al* (12) as follows:

$$\text{mg } O_2 = \frac{h(32)}{22.4}\left[\frac{\dfrac{273\ V_g}{T} + \alpha V_f}{P_o}\right] = kh$$

where

h = pressure change of gas in mm.
V_g = volume of gas in the gas phase, l.
V_f = volume of fluid in vessel, l.
T = temperature, degrees Kelvin.
P_o = mm. of manometer fluid per atmosphere.
α = solubility of oxygen.
k = combined flask constant.

Warburg flasks equipped with separate center wells allow additional refinement in technique, in that separate anodic and cathodic reactions can be studied. Such separation of corrosion

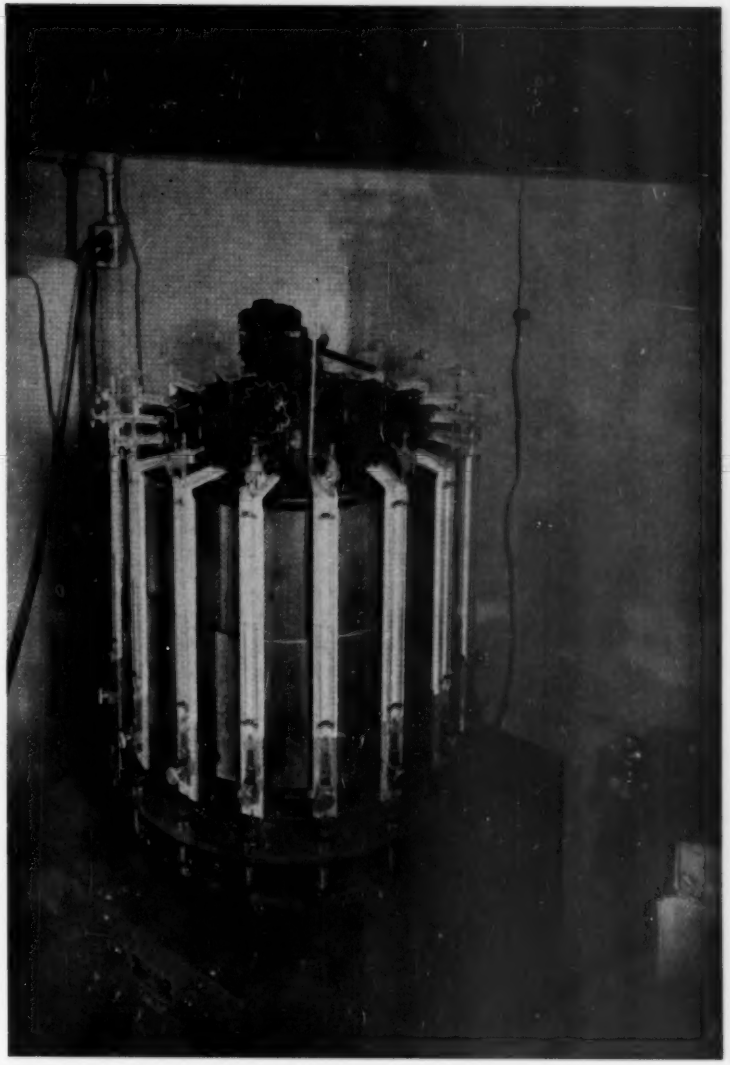

FIG. 1.—WARBURG RESPIROMETER.

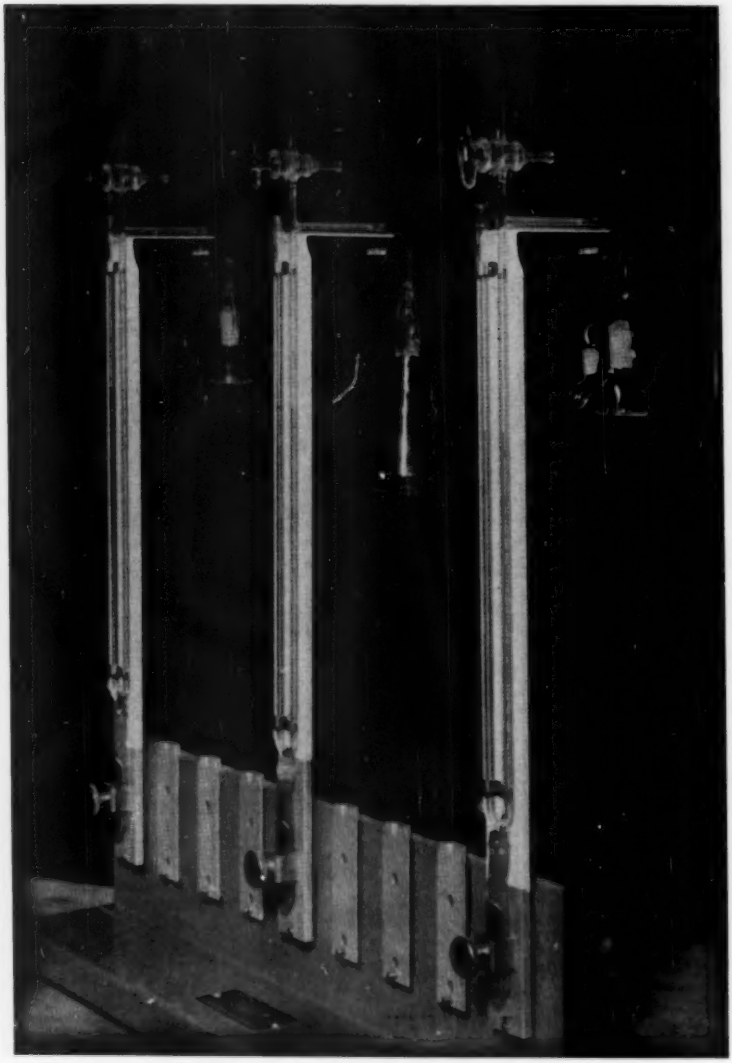

FIG. 2.—DETAILS OF MANOMETER AND OXIDATION FLASKS.

reactions is of special importance in studies evaluating corrosion inhibitors and determining their relative effectiveness as cathodic, anodic, or neutral absorption inhibitors.

In corrosion testing, accuracy and reproducibility of results to within only five to ten per cent of theoretical values is common, because of the many variables entering into reaction. Such accuracy can be obtained with the Warburg respirometer. Precision of a higher degree can be obtained with added refinements, but these also require increased laboratory time per experiment. It is a matter for each individual investigator to determine the degree of refinement he finds necessary, to obtain the desirable accuracy in each case.

Three main factors enter into the lack of extreme precision, which must be reported in a fair evaluation of the technique. First, the hydrogen evolved, if any, is not measured separately by the Warburg, and all pressure change is considered to be due to oxygen utilization. Hydrogen evolution is of significance in acid waters, but in neutral and alkaline waters it corresponds to a negligible amount of one to two per cent of the cathode reaction. Speller (13) and Uhlig (14) have reported that hydrogen evolution accounts for a maximum of three per cent of the corrosion reaction in natural waters. Slight reduction in corrosion due to oxygen depletion is another factor to be considered in evaluating the precision of the method. As oxygen is utilized from the corrosion reaction, it is replenished by diffusion from the atmosphere above the liquid. Adequate diffusion of oxygen from the above atmosphere, even under conditions of oxygen utilization many times that in corrosion studies, has been confirmed by Caldwell and Langelier (15) and Dixon (16). The total oxygen absorbed during the course of a corrosion test may be five per cent of the amount available initially, when air is used to replenish that used up, which does not alter the partial pressure of the oxygen to a significant extent. If greater refinement were desired, pure oxygen could be added to each system to replenish that used up in the corrosion reaction.

A third factor in evaluation of the precision of the Warburg respirometer is the oxidation state of the metal being corroded. For zinc, which exists in only one state of oxidation, measurement of the oxygen consumed is a direct measure of the amount

of metal corroded, if it is assumed that hydrogen evolution is negligible. For iron the interpretation may be less direct, since oxygen not only takes part in the corrosion of the metal to the ferrous form, but also oxidizes ferrous to ferric compounds. It may be necessary to determine the relative amounts of ferrous and ferric iron in the corrosion products under certain conditions, but with oxygen saturation, ferrous ions are quickly oxidized to the ferric form in normal tests.

C. Corrosion Specimens

Fine-grade steel wire was used as corrosion specimens. With a diameter of 0.008 in., the wire provided sufficient surface area for rapid uptake of oxygen, which was accurately measurable by manometric means. The wire was made from normal low-carbon steel with the following per cent composition: Fe = 99.5, C = 0.10, Mn = 0.25, P = 0.04 and S = 0.05. The specimens were pickled in 5% hydrochloric acid for 4 minutes at 25°C. prior to the tests.

The steel wire samples were placed into 50 ml water in the reaction flasks, which were of 125-ml capacity. To facilitate handling of the specimens they were coiled into spirals, either a glass stirring rod or a round brass rod being used. With the gently oscillating action of the Warburg respirometer, the samples were in constant motion within the flasks. The constant-temperature water bath was maintained at 20°C. for the corrosion tests. With the reaction flasks and manometers attached, the systems were allowed to remain open to the atmosphere for 15 minutes, in order to obtain uniform thermal equilibrium in all samples. At the end of this time the manometers were closed off, and periodic oxygen-consumption measurements were then made over the desired test intervals.

D. Warburg vs. Weight-Loss Results

Agreement between oxygen-absorption and weight-loss corrosion data was verified by laboratory tests. These studies were made on three-meter samples of the steel wire, which weighed 0.680 gram and had an exposed surface area of 19.2 sq cm per sample. By means of stoichiometric relationships between oxygen and iron present in iron rust, the oxygen uptake was con-

verted to iron corrosion directly. The results were then expressed in mg of iron corroded per sq dm of exposed surface area, the normal corrosion units. The amount of corrosion occurring over a five-day period under various pH conditions, as measured by the two methods, is given in Table 1.

TABLE 1.—CORROSION STUDIES BY OXYGEN-UPTAKE VS. WEIGHT-LOSS METHODS

Oxygen-uptake method (m.d.d.)	Weight-loss method (m.d.d.)
49	47
37	38
22	23
148	161
168	179
173	190
47	53
60	68
61	69
61	70

Measurements of the amount of iron corroded at the various pH levels by the two methods were in quite good agreement, with an average variation of 8% and a range of 1 to 13%. In corrosion testing such variations in results fall within the range of normally anticipated experimental error. The oxygen-absorption results were slightly lower than the weight-loss results in all cases. Although the 8% average variation found between the two methods is not insignificant, its importance is diminished in basic research studies made with the Warburg respirometer alone, since oxygen-uptake results are compared one with the other, and comparisons are not made directly between oxygen-uptake and weight-loss results.

E. Warburg Studies on the Effect of Silicates on Corrosion Inhibition

One of the most important uses of the Warburg technique in corrosion testing is in the evaluation of corrosion inhibitors under many conditions simultaneously. Studies of this type are of particular importance in the field of water supply, since public waters vary in chemical characteristics throughout the country,

and inhibitors which function well in one area may be of little or no benefit in others. The results of a short study, in which only distilled water and Cambridge tap water were used to evaluate the effects of sodium silicate treatment on corrosion inhibition, are presented as an illustration of results which are possible with the Warburg technique.

Since the early 1920's, the use of sodium silicate for corrosion inhibition has become increasingly more common. Texter (8) found that considerable inhibition was obtained over a period of 20 days, as measured by the removal of dissolved oxygen from water in pipeline systems. Other investigators, notably Speller (7), have substantiated these results, but many field installations have not been satisfactorily treated with sodium silicates. This has led to some doubts as to the value of silicates for corrosion control, and especially as to the mechanism of the reactions and influences of environmental conditions, which vary in all water supplies. There has been considerable controversy as to whether silicates are effective due to the silicate itself or whether due to the added alkalinity caused by silicate treatment.

Warburg studies were made on the effects of silicates as corrosion inhibitors. In the first study with distilled water all conditions were maintained identically the same, with the exception of higher silicate dosages in various samples. The results, shown in Fig. 3, indicate greater corrosion inhibition with increased silicate content over a 19-hour test period. No attempt was made to maintain constant pH in the silicate-treated samples, with the result that the pH ranged from pH 6.0 in the untreated distilled-water blank to pH 10.0 in the 1,100-ppm silica solution. It is seen in Fig. 3 that in a 19-hour test period dosages of 22 to 1,100 ppm silica were very beneficial in reducing corrosion. The degree of inhibition varied from 28 to 89% over this range of silicate concentrations.

The effect of increased alkalinity with sodium silicate treatment was observed in succeeding tests with Cambridge tap water. Sodium silicate concentrations of 17, 49, 115 and 550 ppm were studied, with duplicate samples having the same pH maintained by sodium hydroxide addition. Some of the results are shown in Fig. 4. In these studies, the effect of increasingly high sodium silicate concentrations was to decrease the amount of corrosion as

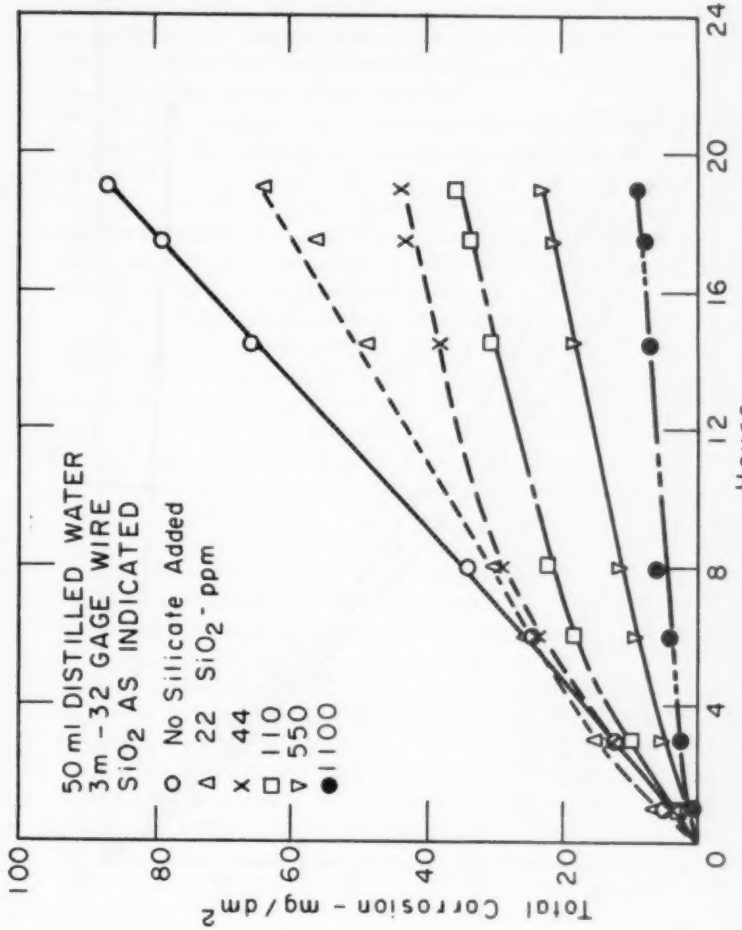

FIG. 3.—EFFECT OF SILICATES ON CORROSION OF IRON.

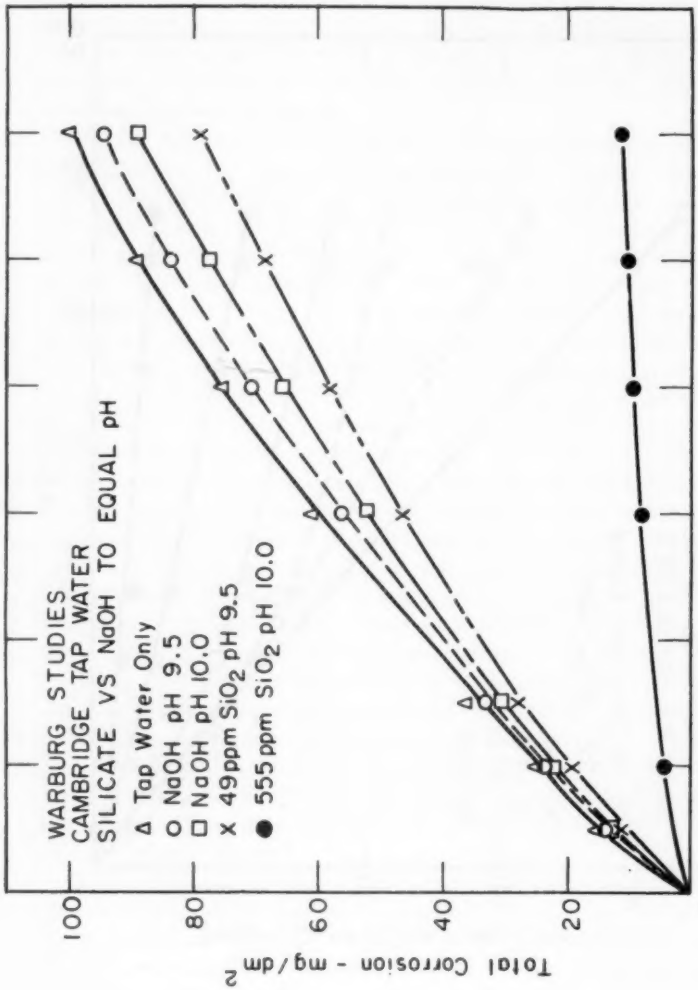

FIG. 4.—EFFECT OF SILICATE VS. NaOH ON CORROSION OF IRON.

measured by oxygen uptake, while pH control by sodium hydroxide did not produce the same inhibitory effect. Silicate concentrations of 49 and 555 ppm reduced corrosion by 21 and 89%, respectively. It follows from these short-term studies that silicates are beneficial in reducing corrosion by an amount over and above that due to the pH factor alone.

In the previous study comparisons were made between sodium silicate solution at various concentrations and sodium hydroxide solutions at equivalent pH levels. Corrosion was found to be less in the silicate solutions in all cases. These studies indicated that inhibition was due to the concentrations of silica, as well as to the expected inhibition obtained by the addition of an alkaline compound to water.

Two studies were made in which the pH levels were maintained constant at pH 8.0 and pH 9.0, while silicate concentrations were allowed to vary. Different silicate concentrations were obtained by adding silicates with Na_2O:SiO_2 ratios of 1:1, 1:2 and 1:3.3. The very alkaline 1:1 ratio silicates attained the desired pH level quickly with little SiO_2 present, while more silicate was added to reach the same pH level in the case of the less alkaline compound. The results of the tests at pH 8.0, shown in Fig. 5, indicate clearly the inhibitory effects of increased silicate concentrations, as compared with sodium hydroxide solutions having the same pH. After 48 hours of corrosion, the inhibition obtained in the 4-, 20-, and 26-ppm silicate solutions was 20, 34 and 49%, respectively.

In studies at pH 9.0, much more effective corrosion inhibition was obtained with increasing amounts of silica. These results are shown in Fig. 6. A most striking difference was observed between the corrosion rate in a pH 9.0 solution of sodium hydroxide, as opposed to that in an identical pH solution obtained by adding sodium silicate. This important factor, not disclosed from the results of other types of experiments, indicates that the efficiency of silicate inhibition is a function of pH.

Many writers have been perplexed by the inconsistency of corrosion-inhibition results when feeding sodium silicate to potable waters transported in steel pipes. Some of the inconsistencies have been attributed to differences in ionic concentrations caused by the impurities in natural waters. Among these ions are

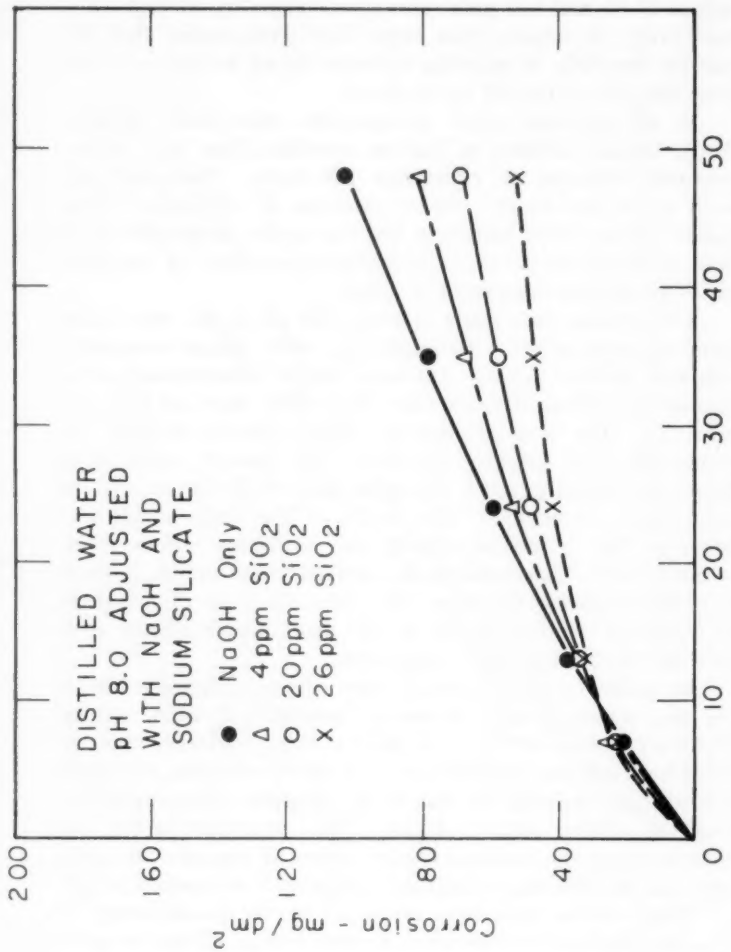

FIG. 5.—EFFECT OF SILICATES ON CORROSION OF IRON AT pH 8.0.

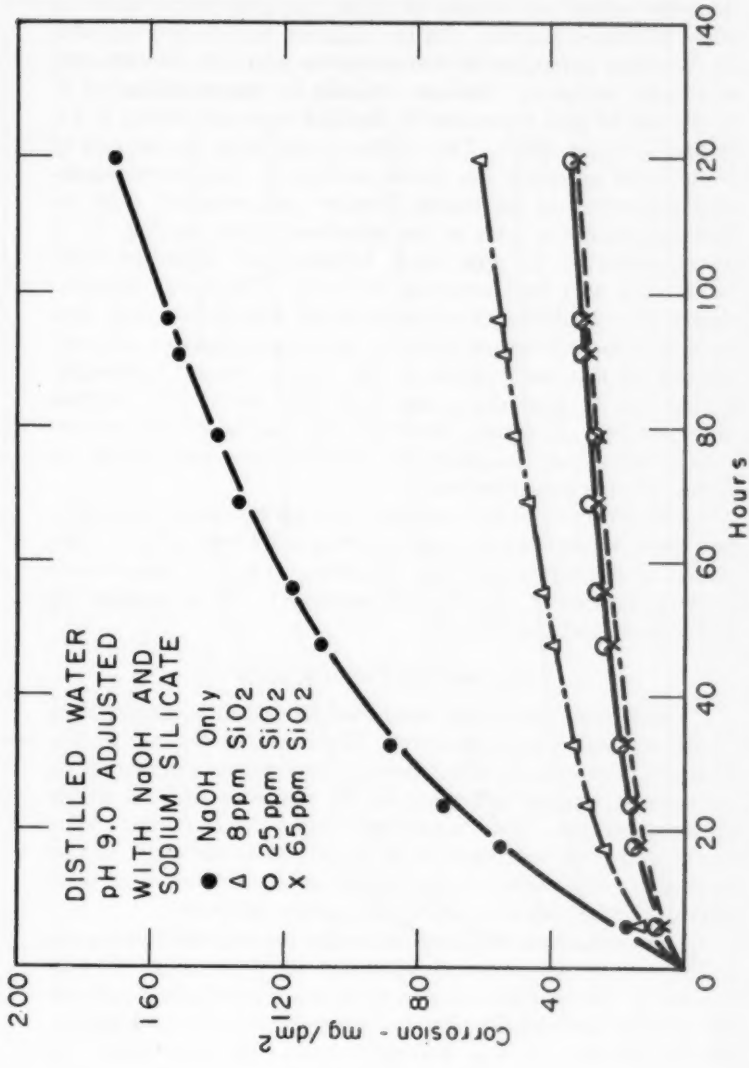

FIG. 6.—EFFECT OF SILICATES ON CORROSION OF IRON AT pH 9.0.

chlorides, which are known to cause corrosion acceleration in many soft-water supplies. An investigation was carried out with the Warburg apparatus to determine the effect of chloride ions on silicate inhibition. Calcium chloride in concentrations of 0, 10, 20 and 40 ppm was added to distilled water containing 0, 11, 44 and 110 ppm silica. The results of this study at the end of 48 hours of corrosion are shown in Fig. 7. The corrosion-accelerating effect of increasing chloride concentrations with no inhibitor present is seen in the uppermost curve in Fig. 7. A concentration of 11 ppm silica followed the untreated-water curve quite well but somewhat below it. There was approximately 20% inhibition of corrosion in all chloride solutions, but the corrosion-accelerating effect of increased chlorides was not reduced by this concentration. The curves became noticeably flattened at 44 ppm silica, and even more so in the 110-ppm silica solutions. It is seen, therefore, that higher silicate concentrations effectively mitigate the adverse corrosion effects of higher chloride concentrations.

The effects of other ions have also been studied, but more data must be obtained in order to draw valid conclusions. This method of measuring corrosion will prove to be very effective in studying the many variables of interest to those engaged in corrosion-control activities.

Summary and Conclusions

Experiments have been conducted using a new approach to corrosion-reaction measurements. This involves the use of the Warburg respirometer, which permits continuous observation of the rates of oxygen utilization in the corrosion of steel in an aqueous medium. This apparatus employs manometric techniques which are described in the paper. It is the claim of the authors that this method is less cumbersome and more rapid than other oxygen-depletion methods, yet equally accurate.

This paper cites the result of studies on the effectiveness of sodium silicate in corrosion inhibition in steel pipes. It was possible to differentiate the effects of several variables, such as pH, calcium and chloride ion concentrations on corrosion inhibition by silicates. It was definitely shown that the efficacy of silicates was a function of the pH of the water and silicate con-

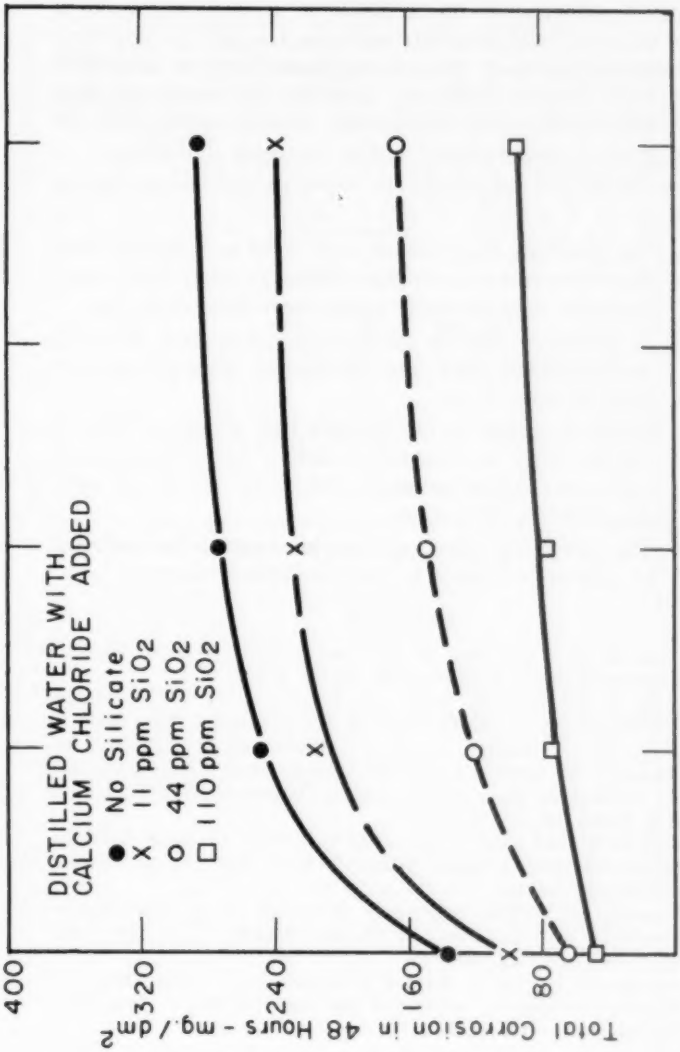

FIG. 7.—EFFECT OF SILICATES ON IRON CORROSION—48-HOUR TEST.

centration. Admittedly, the addition of sodium silicate to a neutral water will add alkalinity and raise the pH. Some writers have claimed that this is the only significant function of sodium silicate as a corrosion inhibitor. However, the results of these studies with the Warburg respirometer indicate clearly that the silicate group is the important one in corrosion inhibition.

On the basis of the studies the following conclusions may be drawn:

1. The Warburg respirometer is a rapid and flexible technique for use in corrosion studies to investigate many variables simultaneously under controlled conditions.
2. Statistical correlation can be achieved between Warburg oxygen-uptake data and weight-loss measurements in iron corrosion tests.
3. Initial Warburg studies indicate that alkalinity alone is not the cause of corrosion inhibition by sodium silicate treatment. More important inhibitory effects are produced by the silicate group.
4. The deleterious effects of chloride ions on the corrosion of steel are mitigated by sodium silicate treatment.

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ACKNOWLEDGMENT

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PROCEEDINGS

April 1959 Meeting

Metacomet Country Club, East Providence, R. I.

Thursday, April 16, 1959

The Southern New England meeting of the New England Water Works Association was held in East Providence, R. I., on Thursday, April 16, 1959, with 225 members and guests present.

The group first met at the Administration and Operational Building of the Water Supply Board of the city of Providence on Academy Ave., Providence. Guided tours were provided, as well as refreshments of coffee and doughnuts. An inspection of the plant and facilities of B-I-F Industries, Inc., Harris Ave., followed.

Luncheon was held at the Metacomet Country Club in East Providence, after which President Clarence L. Ahlgren introduced the Honorable Walter H. Reynolds, Mayor of Providence, who spoke as follows:

"It is a privilege for me this afternoon to have the opportunity of welcoming to the city of Providence the representatives of the New England Water Works Association. Lest I be accused of taking in too much territory, let me hasten to recognize that through the courtesy of the Metacomet Country Club I am addressing you from the city of East Providence. Perhaps, to keep the records straight, it would be best to regard this as a belated greeting and welcome to the city of Providence, in which you spent the greater part of this morning.

"The city of Providence has many activities and many functions which it considers of outstanding merit and in which it takes an honest and workmanlike pride. In the forefront of these is the organization and service of the Providence Water Supply Board. From its early and well-planned commencement to its present state of high efficiency under the very able and

competent Chief Engineer, Phil Holton, the Providence Water Supply Board has come to serve not only the residents of the city of Providence, but as of today, approximately half of the population of the State of Rhode Island. I think one index of the industry and thrift of this system is that we are only now preparing to institute the first increase in water rates since 1923. I don't need to remind anyone present of the price history of any other commodity which you may care to name.

"We regard the Providence water system as among the best —if not the very best—water system in the world from whatever point of view you may wish to examine it. It is perhaps for this reason that we seem to be constantly required to defend our system and our consumers. In addition to liberty, it seems that 'eternal vigilance' is the price of other things as well. During the current year, for example, we have had suggestions—indeed, specific and detailed recommendations—from an outside source that our system be turned over for operation to the State of Rhode Island. I trust we have been successful in rebutting this proposal, which would charge our consumers twice for a system now nearly paid for, and which would not add one single drop to available water supplies.

"We appreciate water-supply problems in far outlying areas. We are eager to see adequate amounts of water available to all of the people of this state, but the only sensible and constructive way to bring this about is for the State of Rhode Island to develop new sources of supply, if it wishes truly to contribute in this regard.

"Also we have had introduced in the General Assembly this year a bill which would open our watershed and reservoir system to boating, fishing, and other recreational uses. Recreation-minded as we are, and I would note the city of Providence has approximately doubled its expenditures for recreation in the past 10 years, we are compelled to oppose this measure also—an action upon which I believe the majority of those present would agree.

"Again, permit me to thank you for your visit to our city of Providence. We are happy to welcome you and always pleased

to have the opportunity to display one of our finest assets—our Providence Water Supply.

"Thank you and good afternoon."

A paper on "A History of the Providence Water Supply and Its Treatment Methods" was read by John J. Collins, Jr., Superintendent of Filtration, Water Supply Board, Providence, R. I.

A paper on "Use of Butterfly Valves on Water Distribution Systems" was read by Arthur E. Hatch, Valve Engineer, B-I-F Industries, Inc., Providence, R. I.

May 1959 Meeting

Manchester Country Club, Manchester, N. H.

Thursday, May 21, 1959

More than 200 attended the Northern New England meeting of the New England Water Works Association on Thursday, May 21, 1959, at Manchester, N. H. The members and guests met at the Manchester Country Club, where coffee and doughnuts were served prior to the boarding of buses for an inspection tour of the Manchester Water Works forestry and sawmill operations.

Luncheon was served at the Manchester Country Club, where greetings of the city of Manchester were given by the Mayor, Hon. Josaphat T. Benoit.

The following resolution was adopted by unanimous vote of the members present:

"A Resolution Concerning the Proposed Revision of the Public Health Service Drinking Water Standards with Particular Reference to the Filtration of Surface Water Supplies

"WHEREAS: The New England Water Works Association is vitally interested in the quality of water supplied to the public, and

"WHEREAS: The Public Health Service Drinking Water Standards generally used as quality guides are currently under consideration for revision, and

"WHEREAS: It has been brought to the attention of the New England Water Works Association that a recommendation has been made to the

United States Public Health Service that the revised drinking water standards include a provision that all surface-water supplies should be filtered, and

"WHEREAS: A large portion of the population of New England is served water derived from upland sources with clean, properly supervised watersheds, the waters of which are of suitable quality without filtration, and

"WHEREAS: The New England Water Works Association approves the policy to maintain the control of domestic water-supply reservoirs in the hands of the State Health Agencies and of the water purveyors and the water consumers,

"NOW, THEREFORE, BE IT RESOLVED: That the New England Water Works Association opposes any requirement in the revised Public Health Service Drinking Water Standards that all surface-water supplies should be filtered."

A paper on "Manchester Water Works Forestry Operations —Fact or Fancy" was read by Aldis J. Christie, Forester, Manchester Water Works, Manchester, N. H.

A paper on "Water Department Planning" was read by Clarence E. Ferry, Superintendent of Distribution, Manchester Water Works, Manchester, N. H.

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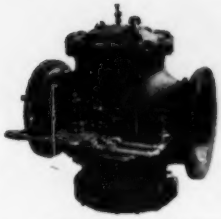


Controls elevation of water in tanks, basins and reservoirs

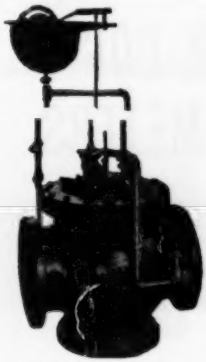
ALTITUDE VALVE

1. Single Acting
2. Double Acting

Maintains desired discharge regardless of change in rate of flow pressure

REDUCING VALVE

Regulates pressures in gravity and pump systems; between reservoirs and zones of different pressures, etc.



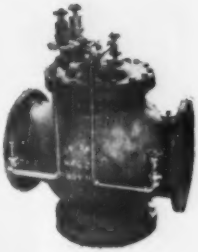
Maintains levels in tank, reservoir or basin

1. As direct acting.

2. Pilot operated and with float traveling between two stops, for upper and lower limit of water elevation.

FLOAT VALVE

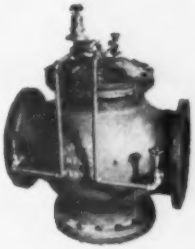
A self contained unit, with controls three or more automatic



COMBINATION VALVE

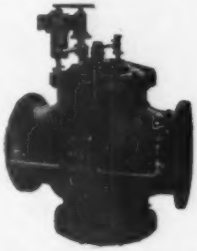
Combination automatic control both directions through the valve.

Maintains safe operating pressures for conduits, distribution and pump discharge



SURGE-RELIEF VALVE

Electric remote control—solenoid or motor can be furnished



REMOTE CONTROL VALVE

Adapted for use as primary or secondary control on any of the hydraulically controlled or operated valves.

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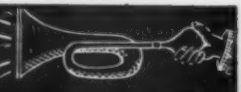

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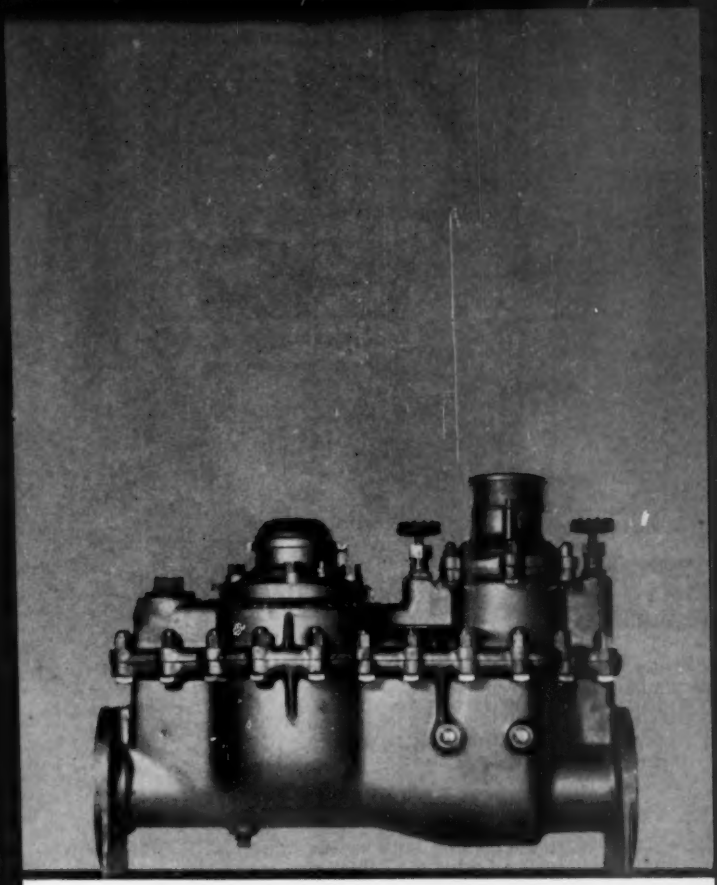

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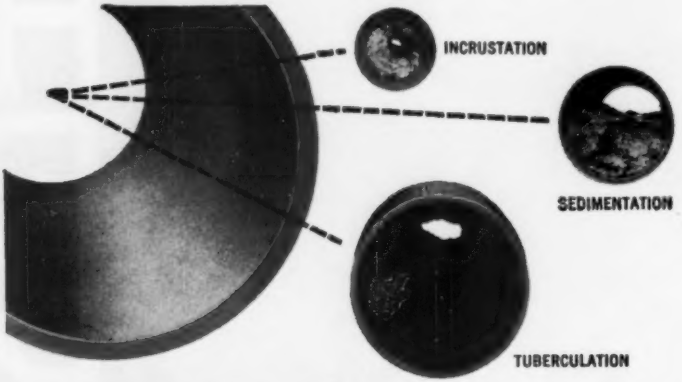

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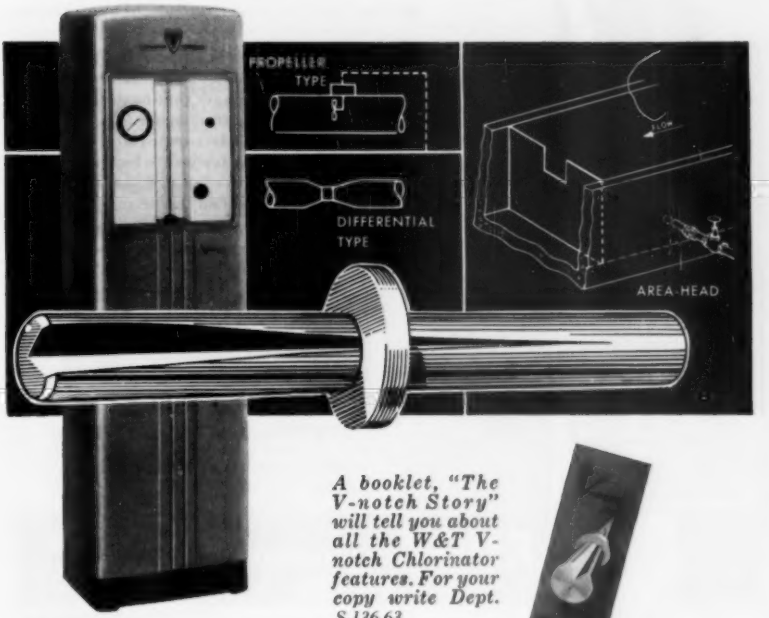

A booklet, "The V-notch Story" will tell you about all the W&T V-notch Chlorinator features. For your copy write Dept. S-136.63.

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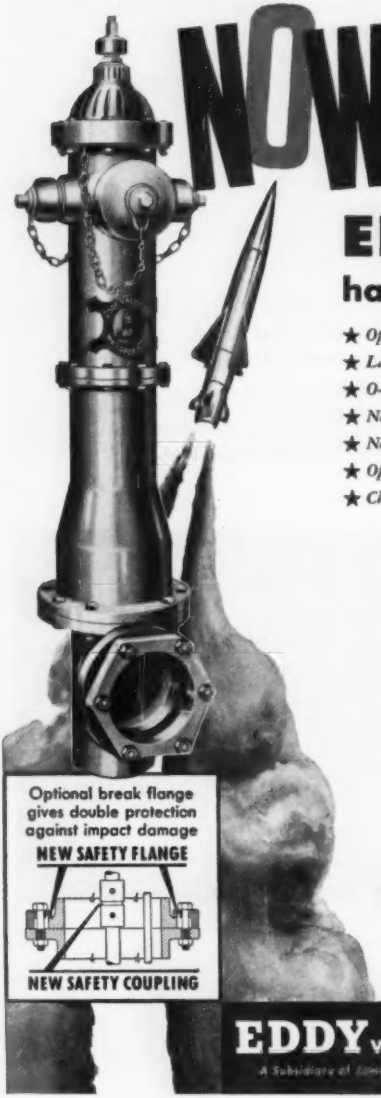

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. . . that conform to A.W.W.A. specifications in all respects

FIG. 56
- Inside Screw
- Non-Rising Stem
- Parallel Seats
- Bell Ends

FIG. 571X
- Inside Screw
- Non-Rising Stem
- Parallel Seats
- Mechanical Joint Ends

FIG. 591
- Inside Screw
- Non-Rising Stem
- Parallel Seats
- Flanged Ends

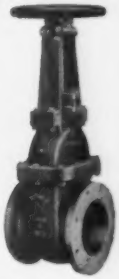

FIG. 566
- Outside-Screw-and-Yoke
- Rising Stem
- Parallel Seats
- Flanged Ends

Construction features . . .

Conventional stuffing box

with adjustable gland has ample space for packing that conforms to Federal specification HH-P-106c. The bottom face of the stuffing box flange is faced smooth to form bearing surface for stem thrust collar.

O-Ring seals

once installed no adjustment of any kind is required. The top O-Ring is the dirt seal and the bottom O-Ring is the pressure seal.

Operating nut

is Higher Strength Cast Iron. The base flange, with arrow indicating direction to open, is shaped to permit access from ground surface to adjust gland nuts with an extension socket wrench.

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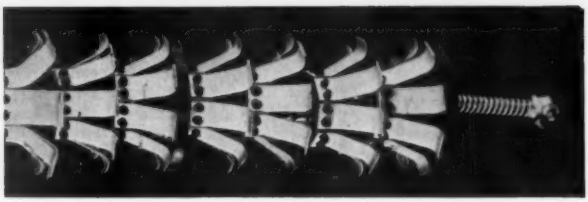

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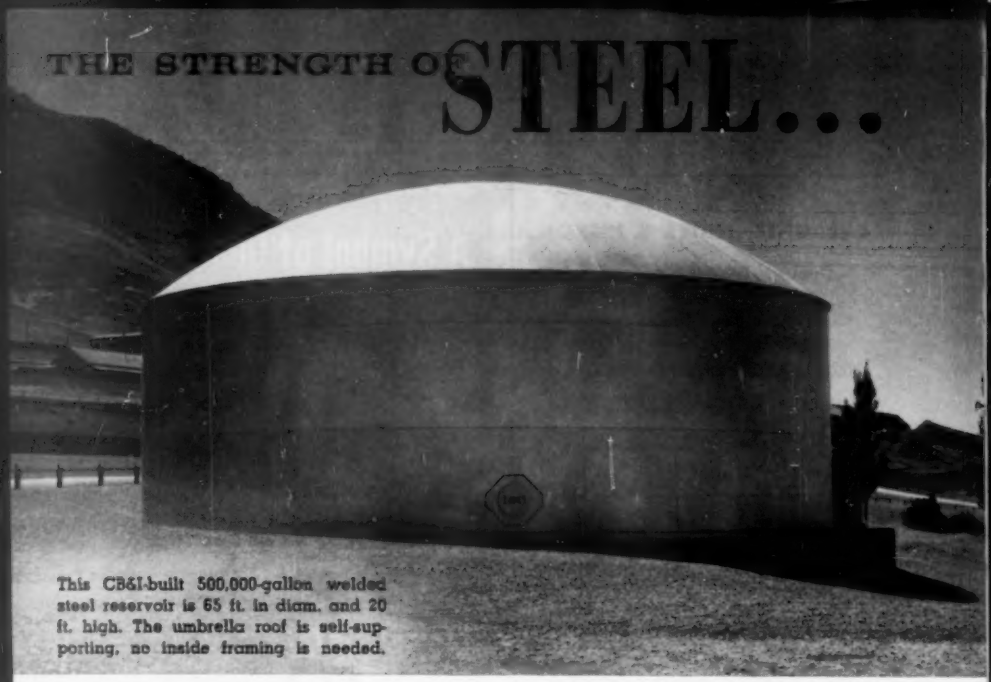

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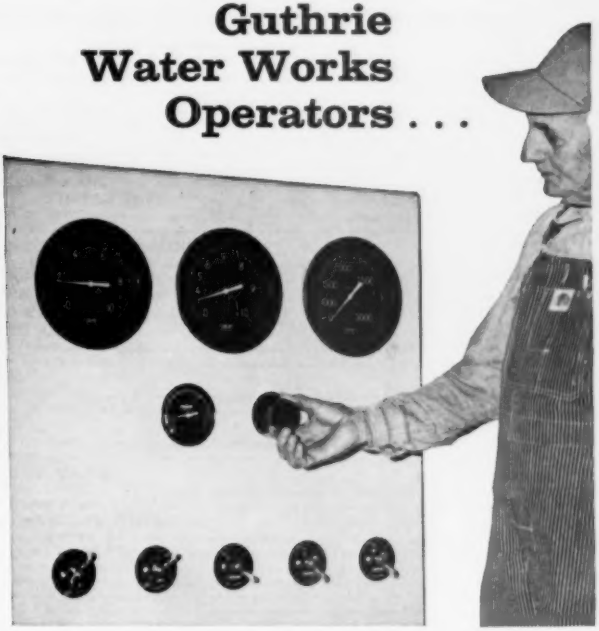

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